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Peer Review for "Methodology for Evaluating Fleet Protection of New Vehicle Designs: Application To Lightweight Vehicle Designs"

DISCLAIMER

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1.0 INTRODUCTION

This document is the Peer Review Report for a study conducted by George Washington University (GWU), for the Division of Structures and Restraints Research at the National Highway Traffic Safety Administration, a modal administration of the U.S. Department of Transportation. This document contains the peer review comments from the three peer reviewers selected for this project. The verbatim copies of the reviewers' comments can be found in Section 5 to 7 of this report, and the peer reviewers' curriculum vitae can be found in Appendix A. Also included in this document are GWU's responses to the peer review comments. In order to help the readers finding out how GWU responded to the peer review comments in the final report, the responses are documented in a tabular format in this document, including the reviewer's name, original comments, commented section in the report, GWU's responses, and where the GWU's responses are located in the final report.

2.0 CHARGE TO PEER REVIEWERS

A Study of Self and Partner Protection of Lightweight Vehicle Designs Using Structural Modeling:

I. Background

The National Highway Traffic Safety Administration is an agency of the U.S. Department of Transportation. As part of its mission, NHTSA has been issuing Corporate Average Fuel Economy (CAFE) standards under the Energy Policy and Conservation Act (EPCA) for the last 30 years. EPCA requires the agency to establish average fuel economy standards for passenger cars and light trucks at "the maximum feasible average fuel economy level that the Secretary of DOT decides the manufacturers can achieve in that model year." When setting "maximum feasible" fuel economy standards, the agency is required to "consider technological feasibility, economic practicability, the effect of other motor vehicle standards of the Government on fuel economy, and the need of the United States to conserve energy." The Energy Independence and Security Act (EISA) was enacted on December 19, 2007, and amended EPCA by mandating, in addition to passenger car and light truck standards being set at the maximum feasible level in each model year (MY), that the model years 2011 to 2020, CAFE standards be set sufficiently high to ensure that the industry-wide average of all new passenger cars and light trucks, combined, is not less than 35 mpg by MY 2020.

In fulfillment of its EPCA and EISA requirements and in response to President Obama's request to create a coordinated and harmonized National Program for motor vehicle efficiency and emissions standards, NHTSA recently published a joint Notice of Proposed Rulemaking (NPRM)[1] with the Environmental Protection Agency (EPA) to set CAFE standards under EPCA/EISA and greenhouse gas (GHG) standards under the Clean Air Act for passenger cars and light trucks manufactured in MYs 2017-2025. Based on public information and information NHTSA gathered about how vehicle manufacturers plan to comply with CAFE standards in those model years, the agency anticipates that the industry will make use of vehicle mass reduction as a means for reducing vehicle fuel consumption in the future. NHTSA's rulemaking analyses have employed "mass reduction" as a technology option for compliance modeling purposes. In developing the MYs 2017-2025 NPRM, NHTSA has become aware of several recent studies that appear to show significantly greater amounts of mass reduction than NHTSA has previously analyzed in MYs 2012-2016 final rule. Also several vehicle manufacturers have stated publicly that they are pursuing mass reduction as one major technology in meeting the future CAFE target. NHTSA

[1] A link to the NPRM is available at www.nhtsa.gov/fuel-economy.

conducted further research and analysis during calendar year 2011, with the intent of providing more robust data for regulatory analysis when establishing CAFE and GHG standards for MYs 2017 and beyond.

In September 2010 NHTSA provided funding through Inter-Agency agreement (IAA) with Federal Highway Administration (FHWA) to The George Washington University to give technical support to NHTSA research to evaluate self and partner protection of new vehicle designs with changes in power trains and various implementations of lightweighting strategies, through structural modeling and analytical simulations of existing vehicle models.

The vehicle fleet is experiencing a paradigm shift, as vehicle manufacturers are investigating innovative manufacturing technologies and materials, including new power trains, to produce a lighter, more fuel efficient, and environmentally sustainable vehicle fleet which meets new fuel economy requirements. Moreover, given the global economy, growth in the smaller car segments is anticipated (e.g., Focus, Fiesta, Civic, Honda Fit, and Nissan Versa). It is worth noting that upcoming changes in the fleet will include structural redesign of vehicles for power train modifications and that will necessitate recertification by manufacturers for crash performance. Considering a simultaneous change for safety would be more cost effective, i.e., a win-win situation to consider safety improvements along with new power train and lightweighting design changes.

New vehicles designs using advanced lightweight materials are being introduced in the fleet. However, to date, there are not a substantial number of vehicles in the fleet with such new designs. As such, there are concerns that analysis of the historical crash data may not accurately predict future the self and partner crash safety of future lightweight vehicles. Vehicle structural modeling and models of existing vehicle designs provides an opportunity to study vehicle-to-vehicle crash safety of future light-weight vehicle designs.

II. Tasks

In 2011 GWU investigated measures to further improve the self and partner protection of occupants of new vehicle designs through structural and restraint system optimization across real world crash scenarios. An underlying goal was to gain insights from vehicle structural modeling and analytical simulations to evaluate the safety performance of current and forecast light-weighting strategies and power train changes. The effectiveness of potential countermeasures to address any safety consequences was also investigated.

The GWU team has conducted a vehicle design analysis approach to gain insights and help quantify self and partner protection of new vehicles with powertrain and lightweighting design changes, implemented as changes in vehicle weight, size, and structure. The anticipated approach is summarized as follows:

- Use finite element models of baseline and lightweight vehicle designs that were developed for fuel economy cost and feasibility studies.
- Use finite element models of existing vehicle designs that can represent a range of vehicle styles
- Identify and evaluate representative frontal crash configurations for vehicle-to-vehicle and vehicle-to-fixed objects over a range of impact speeds. These crash scenarios should be related to the frequency of real world occurrence for a significant subset of the existing crash environment.
- Develop and perform occupant kinematics simulations for the representative crash configurations. Estimate probability of occupant injury and the combined or overall change in injury risk for all representative crash scenarios.
- Evaluate how occupant injury risk changes for the baseline and lightweight vehicle crash conditions.

NHTSA is seeking reviewers' expert opinion on the methodologies and models used and validity and applicability of the findings from this study. NHTSA asks that reviewers orient their comments on the report toward the following general areas: (1) vehicle structural models; (2) occupant kinematic models, including restraint systems; (3) mapping of crash configurations to real world crash occurrence; (4) combination of occupant injury risks into overall injury estimation; and (5) other comments. These areas will be split into sub-issues in the final charge to reviewers, as shown in Appendix I. Although NHTSA is requesting response to these five areas, reviewers will be expected to identify additional topics or depart from these examples as necessary to best apply reviewers' particular areas of expertise to review the overall study. Reviewers should provide their responses in the table that will be attached to the peer reviewer charge, adding comments as necessary at the end of each table.

Comments should be sufficiently clear and detailed to allow readers to thoroughly understand their relevance to this study. All materials provided to reviewers as well as reviewer comments should be treated as confidential, and should neither be released nor discussed with others outside of the review panel. Once NHTSA and GWU have made the report public, NHTSA will notify reviewers that they may release or discuss the peer review materials and their review comments with others.

III. Performance Period

The peer review shall be finished within two weeks of reception of the report and software files for LS-DYNA and MADYMO models by the reviewer.

IV. Deliverables

Reviewers shall provide the COTR with an MS Word 2007 or newer document containing responses for each item in the table in Appendix 1, adding comments and additional topics as necessary at the end of each table. Additional data files, images, and materials may also be provided as needed.

V. Appendix I. Sample Review Questions

(appendix to the charge letter)

1. Vehicle Structural Models	COMMENTS
Please comment on the suitability and accuracy of the baseline and lightweight FEA models for use in the range of frontal crashes in this study. Also please consider the accelerations and intrusion outputs that were used to drive the occupant simulations	
Please comment on the suitability and accuracy of the four FEA models used to represent the crash partners for use in the range of frontal crashes in this study. Comment on their suitability to represent the general behavior of vehicles in their class.	
ADDITIONAL COMMENTS:	

2. Occupant Kinematic models	COMMENTS
Please comment on the suitability and accuracy of the occupant kinematic models use in this study.	
Please discuss the suitability of the restraint systems and firing times in the occupant kinematic models. Also comment upon the occupant injury measures considered in this study	
If you are aware of other methods to predict occupant injury risk, please suggest why you think they would improve this study and how they might be used.	

3. **Crash configurations and mapping to real world risk of injury**	**COMMENTS**
Please comment on the selection of the vehicle-to-vehicle and vehicle-to-fixed object crash modes selected, the range of impacts speeds and their suitability for evaluating future crash safety.	
Please comment on the methods used to relate the individual crash simulations to their real world frequency of occurrence.	
Please describe the extent to which the use of only frontal crashes limits the applicability of the results to real world effectiveness.	
Please recommend other methods or improvements to map the crash simulations to real world occupant safety risk.	
ADDITIONAL COMMENTS:	

4. Combining individual occupant injury risk into overall injury risk for the fleet	**COMMENTS**
Please discuss the suitability of the methods used to combine the occupant injury risk for the individual crashes into the overall occupant injury risk. Please note any omissions or overstatements.	
Given the assumptions in the vehicle models, fleet representation, crash configurations, and generic occupant interior models, please discuss the suitability of the results for forecasting future safety issues.	

ADDITIONAL COMMENTS:	

5. OTHER POTENTIAL AREAS FOR COMMENT	COMMENTS
Is the methodology used reasonable? Is the study valuable to understand the safety implications for 2017-2025 mass-reduced light-duty vehicles? Please explain why or why not.	
Do the study design concepts have critical deficiencies in its applicability for 2017-2025 timeframe? If so, please describe.	
ADDITIONAL COMMENTS:	

Please provide any comments not characterized in the tables above.

3.0 SELECTION PROCESS

NHTSA therefore selected reviewers with complementary skills to achieve the most balanced review possible. NHTSA considered peer reviewers with technical background in vehicle fleet study, occupant restraint and vehicle design and vehicle crash simulations. NHTSA also tried to select a balanced group of peer reviewers with backgrounds from academia, automotive manufacturers and suppliers. The reviewers were independent, in that none is currently an employee of NHTSA or had a conflict of interest.

The reviewer team, in alphabetical order by last name is:

Kurt Fischer, senior staff engineer at TRW Automotive;

Dr. Clay Gabler, professor, biomedical engineering, associate department head for graduate studies, School of Biomedical Engineering and Sciences, Virginia Tech; and

Dr. Mukul Verma, professor of mechanical engineering (adjunct), Lawrence Technological University; consultant at M. P. Holcomb Engineering Corporation.

The following three sections of this report are the reviewers' original comments verbatim.

4.0 PEER REVIEW COMMENTS FROM KURT FISCHER

1. **Vehicle Structural Models**	**COMMENTS**
Please comment on the suitability and accuracy of the baseline and lightweight FEA models for use in the range of frontal crashes in this study. Also please consider the accelerations and intrusion outputs that were used to drive the occupant simulations	*It makes sense to utilize FE models that were created for previous projects (Accord & Venza). They didn't have to be created and debugged. Creating two versions of the Taurus added a valuable second level of comparison – light weight vs. stiffer. However, SUV's and light trucks are a large portion of the vehicle fleet and to not have a truck as one of the target vehicles may limit the overall effects of lighter vehicles. Light trucks are inherently heavier and potentially have more of an opportunity to reduce weight.* *The accelerations and intrusions from the FE models seemed reasonable. It would be good to see the comparison to actual data (NCAP, IIHS, etc.) to demonstrate a level of correlation.*
Please comment on the suitability and accuracy of the four FEA models used to represent the crash partners for use in the range of frontal crashes in this study. Comment on their suitability to represent the general behavior of vehicles in their class.	*The four vehicle selected did cover the wide range of vehicle sizes from large to small. The Silverado and Explorer are top 20 sales volume vehicles. However, the Taurus and Yaris are not quite as high. A higher volume mid-size car and small car would represent more cars in the fleet.*
ADDITIONAL COMMENTS:	

2. **Occupant Kinematic models**	**COMMENTS**
Please comment on the suitability and accuracy of the occupant kinematic models use in this study.	*MADYMO is a proven tool for evaluating occupant kinematics and loads. It can easily simulate the restraints and the occupant interactions. Plus, run times are relatively short.*
Please discuss the suitability of the restraint systems and firing times in the occupant kinematic models. Also comment upon the occupant injury measures considered in this study	*There was some discussion on the restraint characteristics. However, a more complete summary of the restraint systems for all the vehicles would establish the technology level. Restraints are continuously evolving and summarizing them would 'put a stake in the ground' for this study. Some of the key characteristics would be number of inflator stages, bag volume, venting and tethers, seat belt pre-tensioning and energy management level. If dual stage inflators were used, at what crash conditions were the low output levels used.* *Utilizing the '5-30 rule' is a logical starting point when no actual algorithm was available. It was interesting to see how the 5-30 rule matched known tests.* *The occupant injury measures chosen have a good correlation to estimating injury potential. It is curious why Nij wasn't included nor discussed why it wasn't included. It is commonly used in FMVSS 208 and NCAP.*

If you are aware of other methods to predict occupant injury risk, please suggest why you think they would improve this study and how they might be used.	
ADDITIONAL COMMENTS:	

3. **Crash configurations and mapping to real world risk of injury**	**COMMENTS**
Please comment on the selection of the vehicle-to-vehicle and vehicle-to-fixed object crash modes selected, the range of impacts speeds and their suitability for evaluating future crash safety.	*The range of partner vehicles, fixed objects and relative speeds covered a wide range of crash conditions. They provided a good mix of known tested conditions (NCAP, IIHS, FMVSS 208) and more common vehicle-to-vehicle interactions.*
Please comment on the methods used to relate the individual crash simulations to their real world frequency of occurrence.	*The NASS analysis break down helped verify the majority of crash conditions were covered in the simulations. A small overlap crash would have nice to include since it is becoming a hot topic, but it is understandable that the FE models may not have the robustness to predict such a crash.*
Please describe the extent to which the use of only frontal crashes limits the applicability of the results to real world effectiveness.	*It is understandable to start with the frontal crashes, but in the future it would make sense to look at side impacts. Similar to what was demonstrated in this study, it is expected that the door intrusions in a side impact could increase and potentially increase injury risk.*
Please recommend other methods or improvements to map the crash simulations to real world occupant safety risk.	

ADDITIONAL COMMENTS:

I think this section is the strength of the study. The mapping of NASS data and the parallel created in the simulation study is thorough and well thought out.

4. Combining individual occupant injury risk into overall injury risk for the fleet	**COMMENTS**
Please discuss the suitability of the methods used to combine the occupant injury risk for the individual crashes into the overall occupant injury risk. Please note any omissions or overstatements.	*The path from the simulated crash conditions to the overall injury risk was well thought out and complete. If anything, there may be a slight overstatement due to the fact that the restraints weren't tuned. It was good this was noted in the discussion, but restraint systems are continuously evolving in improving. It is not out of the realm that restraints could reduce those injury risks in lighter vehicles.*
Given the assumptions in the vehicle models, fleet representation, crash configurations, and generic occupant interior models, please discuss the suitability of the results for forecasting future safety issues.	*As far as what was discussed in the study, it demonstrated the potential increased injury risk. However, as stated above the restraints are changing and other technologies are becoming more popular in vehicles like lane departure warning, forward collision warning, adaptive cruise control and automatic braking. These technologies could counteract some of the injury risk seen with the lighter vehicles.*
ADDITIONAL COMMENTS:	

5. OTHER POTENTIAL AREAS FOR COMMENT	COMMENTS
Is the methodology used reasonable? Is the study valuable to understand the safety implications for 2017-2025 mass-reduced vehicles light-duty vehicles? Please explain why or why not.	*The path from the NASS data through the simulations to the final injury risks follows a logical path with reasonable assumptions. The assumptions always add a level of uncertainty, but in this case they are well explained and evaluated making them reasonable. As stated earlier, technologies today will be improved by the 2017-2025 time frame, but for an initial analysis this study gives a glimpse in the future of what will have to change to keep occupants safe.*
Do the study design concepts have critical deficiencies in its applicability for 2017-2025 timeframe? If so, please describe.	*Automotive technologies have changed for the past hundred years and will continue to do so. However, this study effectively evaluated potential areas where changes could be required to maintain the current level of occupant safety.*
ADDITIONAL COMMENTS: There were some typo's. Page 7, paragraph 1, line 7: 'Figure 2-2' should be 'Figure 3-2' Page 8, paragraph 1, line 2: 'Figure 2-4' should be 'Figure 3-4' Page 14, 'PU (Pickup) Trucks…' should be indented Page 29, paragraph 2, line 9: '… for Explorer …' should be '… for the Explorer…' Table 3-12, 3-13, 3-14, and 3-15 should have units for mph and seconds. Table 3-18 should also have units. Page 60, 'Overall risk of the Taurus BL in SV is 0.15%=0.75x0.10 (not 0.15)…'	

5.0 PEER REVIEW COMMENTS FROM DR. CLAY GABLER

Review of

A Study of Self and Partner Protection of Lightweight Vehicle Designs Using Structural Modeling

Clay Gabler

17 June 2013

Following is a review of the report “A Study of Self and Partner Protection of Lightweight Vehicle Designs Using Structural Modeling” draft version dated May 2012 by Samaha et al. The review comments presented below were structured to follow the requested review comments outlined in the letter “Charge to Peer Reviewers of ‘A Study of Self and Partner Protection of Lightweight Vehicle Designs Using Structural Modeling’” received from NHTSA in late May 2013. The review requests for comment are underlined in the discussion which follows.

General Comments

The objective of this study was to develop a Systems Model of the U.S. traffic crash environment to allow the crashworthiness of a proposed new vehicle design to be evaluated across the full range of expected crash conditions. In this study, the safety benefit or disbenefit of reducing vehicle weight to meet expected new CAFE regulations was examined as a demonstration of this Systems Modeling methodology. The subject report refers to this process as “lightweighting” and the resulting designs as “lightweighted vehicles.” Systems Modeling is an important method for evaluating crashworthiness which avoids many of the difficulties of single speed, single vehicle crash test evaluation. The study is nicely formulated and the report is well-written.

Systems Modeling is, in my opinion, precisely the method which NHTSA and automakers should use when evaluating the crashworthiness of existing or proposed vehicle designs. Vehicles which are single-mindedly designed to perform well in a handful of high severity crash tests, e.g., NCAP, may exhibit suboptimal occupant protection in lower severity – but more prevalent – real world crashes. In contrast, the Systems Modeling approach, presented in this study, evaluates vehicle crashworthiness across the full spectrum of crash modes, collision partners and potential drivers which a vehicle is likely to experience on U.S. highways. The result is a much more robust measure of societal injury risk than can hope to be achieved with a single crash test. The Systems Model proposed in this study is a bold new method for crashworthiness evaluation for which both NHTSA and the report authors should be commended.

I. Vehicle Structural Models

Please comment on the suitability and accuracy of the baseline and lightweight FEA models for use in the range of frontal crashes in this study. Also please consider the accelerations and intrusion outputs that were used to drive the occupant simulations

I concur with the report's conclusions that the Venza FE model does not appear to be correct. As shown in Figure 4-25, the 20 and 25 mph frontal offset crash pulses from the FE model are suspect. In addition, the study reports that many of the Venza FE models terminated abnormally. As recommended by the report, the model should be validated before reporting any findings using the Venza model.

Please comment on the suitability and accuracy of the four FEA models used to represent the crash partners for use in the range of frontal crashes in this study. Comment on their suitability to represent the general behavior of vehicles in their class.

The choice of the 2001 Ford Taurus, 2003 Ford Explorer, 2007 Chevy Silverado, and 2010 Toyota Yaris are reasonable surrogates to represent the collision partners which broadly cover the range of expected passenger vehicle collision partners which the lightweighted vehicles could expect to encounter.

The only caveat is that two of the FE models (the 2001 Taurus and 2003 Explorer) are FE models of 10+ year old designs. The automakers have made numerous structural modifications to their vehicle designs in the last 10 years in response to tests such as the IIHS frontal-offset crash tests and to improve crash compatibility under the voluntary "Enhancing Vehicle-to-Vehicle Crash Compatibility Agreement (EVC)" established in 2003. I raise this issue as the goal of the Systems Model is to project the performance of lightweighted vehicles in future fleets, perhaps for the 2018 timeframe, when few of these 2001-era vehicles will still be on the highways.

The FE models of the older Taurus and Explorer may still be suitable for the Systems Model, but the report would be improved by examining and discussing this issue. One way to do this would be compare crash test results, e.g. estimates of vehicle stiffness, crash pulse, intrusion, of these older vehicles with their newer 2013 and later counterparts.

Additional Comments

The report (Table 3.7, p.20) indicates that the 2010 Toyota Yaris model is still under development and that the model has not yet been validated against NCAP crash test. It is unclear if this was the status of the model when the study was performed. If an unvalidated model was used, is the intent to rerun the results after validation of the Yaris model?

II. Occupant Kinematic Models

Please comment on the suitability and accuracy of the occupant kinematic models use in this study.

One crucial assumption and limitation, acknowledged in the report, is that the study uses the same restraint system for both the baseline vehicles and the lightweight variants of these vehicles. The automakers highly optimize restraint systems for each vehicle design, and it would be unlikely that the lightweight variants of the target vehicles would have the same restraint systems as their baselines. The restraint systems optimized for the lightweight variants could be expected to have a lower injury risk than if the baseline restraint system was installed without alteration in the lightweight variant. Hence, the use of generic restraint systems would likely contribute to overestimation of the injury risk for the lightweight variants.

The Toyota Venza, one of the target vehicles, is equipped with a knee airbag. However, the knee airbag was not included in the occupant simulation models of the Venza. I would expect that the presence/absence of the kneebag would substantially affect occupant responses.

Section 4.4 provides a nice discussion of the limitations of the occupant models. This section can be used as a roadmap for further development of the occupant models. Limitations include lack of a model steering column linkage system which is required to accurately model steering wheel intrusions. There is also a need in general for improved modeling of occupant compartment intrusions. This first iteration of the Systems Model has decoupled vehicle structural modeling (performed in LSDYNA) from occupant modeling (performed in MADYMO). Intrusions from LSDYNA are used as prescribed inputs to MADYMO. While this is a reasonable approach for this first iteration of the Systems Model, there is a need for much more accurate modeling of occupant compartment intrusion. I concur with the report's recommendation that intrusion and occupant modeling be conducted in LSDYNA or a similar FE code in future iterations of the Systems Model.

Please discuss the suitability of the restraint systems and firing times in the occupant kinematic models. Also comment upon the occupant injury measures considered in this study

Airbag firing algorithms are one of the most closely guarded trade secrets in the auto industry. They were not available for this study, nor should they be expected to be available in future studies. As an alternative, occupant impact response models in this study used a "5-30" surrogate firing time algorithm. This is a reasonable surrogate – indeed it is probably the only reasonable alternative.

The report presents a nice analysis which checks the "5-30" algorithm against the actual airbag firing times observed in crash tests. However, this validation was limited to available crash tests (a 47kph frontal-offset Transport Canada crash test for the Taurus and a 56kph full frontal NCAP crash test for the Yaris). It is unknown however how well these results will generalize to other crash modes, e.g. frontal-pole crashes, differing degrees of frontal-offset, or lower impact speeds. Airbag firing times and deployment strategies are likely to vary with crash mode and with occupant position.

The report on validation of the Venza airbag firing timing is incomplete. The report does not identify which crash test was used to obtain the Venza airbag firing time, and unlike the Taurus and the Yaris, the report also does not present the shoulder belt loads vs. time or vehicle displacement history for the Venza. It would be useful to identify the crash test and include these plots so that the Venza airbag firing time can be checked.

Follow-on studies should check the "5-30" algorithm against actual firing times recorded in frontal-offset and pole crash tests. A second approach which should be considered would be to obtain airbag firing times that are recorded in real-world EDR data. The EDR data could provide the firing time for both the first and second deployment stages as a function of crash mode, delta-V, and occupant position.

<u>If you are aware of other methods to predict occupant injury risk, please suggest why you think they would improve this study and how they might be used.</u>

The methods used by this study to assess occupant injury risk follow accepted practice used in the crashworthiness research community.

<u>Additional Comments</u>

N/A

III. Crash configurations and mapping to real world risk of injury

<u>Please comment on the selection of the vehicle-to-vehicle and vehicle-to-fixed object crash modes selected, the range of impacts speeds and their suitability for evaluating future crash safety.</u>

One challenge that this study has faced is how to obtain a fleetwide distribution of impact speeds. Impact speed is not recorded in NASS/CDS, NASS/GES, or FARS. NASS/CDS does contain delta-V and barrier equivalent speed (BES), but neither delta-V nor BES is a measure of impact speed. This has been a challenge for every Systems Model that I am aware of. Impact speed is simply not available from the U.S. in-depth databases.

The study used BES as a surrogate for impact speed, however in a very clever way. FE simulations were run using BES, but primarily as a simulation initial condition to get a crash pulse. The crash pulse was then used to drive the occupant models. The essential effect of this approach was to ensure that the resulting crash pulses were applied with a reasonable statistical weight.

As an aside, I was pleased to see that the study chose to use BES rather than relying on delta-V. Approximately half of delta-V values in NASS/CDS are unknown. The percentage of missing delta-V values is closer to 75% missing in single vehicle collisions with fixed objects. The report indicates that BES was coded in 68% of their NASS cases of interest while delta-V was only available in 59% of the cases. BES values are known for a much larger proportion of the cases in NASS, but BES has been overlooked by many previous studies as a valuable measure of crash severity which avoids some of the difficulties associated with delta-V estimation.

Now that the FE modeling is complete, the study should check out the validity of their assumption that BES can be used as surrogate for impact speed. The distribution of the delta-V values computed in the FE models should be easy to check against the corresponding distribution of delta-V obtained from NASS/CDS for these vehicle models. If BES as impact speed was a good assumption, the two delta-V distributions should be fairly comparable.

Future studies should consider other methods of obtaining vehicle impact speed distributions. One promising approach would be to use the vehicle pre-crash speed which is recorded in EDRs in real-world crashes. A second approach would be to seek out and analyze in-depth crash databases which, through enhanced reconstruction methods, have determined impact speed for large numbers of cases. In the U.S., one such candidate database is the NCHRP 17-22 database of single vehicle crashes. A second possibility would be to use European or other international in-depth databases which have reconstructed impact speed.

<u>Please comment on the methods used to relate the individual crash simulations to their real world frequency of occurrence.</u>

The report should present the distribution of driver age in the U.S. population of belted drivers. It is important to carefully evaluate the study decision to limit the analysis to drivers of age 16 to 50 years of age. My concern is that older drivers are at substantially higher risk of injury in crashes than drivers in this younger age range. Older drivers also account for a substantial fraction of drivers regardless of injury level. An analysis of NASS/CDS 1997-2011, which I conducted for this review, indicated that belted drivers 51+ years old account for 23% of drivers, but over 34% of MAIS3+F drivers. Limiting driver age to 16-50 year olds was used as a simplifying assumption in this first iteration of the study. However, this assumption may have a potentially huge influence on the study findings. The report should discuss how omitting older drivers affects the likely findings.

Figure 3-7 indicates that cars and pickup trucks have the same risk of injury up to 60 kph. The outlier in this graph appears to SUVs. The figure indicates that SUV risk is lower than both cars and pickup trucks across the range from 0 to 60 kph. This is counter-intuitive. I would expect that pickups are more like SUVs than like cars. It would be useful for the report to discuss this finding.

<u>Please describe the extent to which the use of only frontal crashes limits the applicability of the results to real world effectiveness.</u>

This study does not consider the performance of the target lightweight vehicles in front-side or front-rear crashes. Lightweighted vehicles are likely to be fitted with stiffer frontal structures which could make these vehicles more aggressive or incompatible with their side struck collision partners.

Please recommend other methods or improvements to map the crash simulations to real world occupant safety risk.

The challenge which this project faces is to predict the societal risk incurred by lightweight vehicles and their collision partners in a future fleet. The report does not speculate when these lightweight vehicles might compose a significant fraction of the fleet, but a reasonable estimate would be five years from now or 2018. The report is correct in stating that one limitation of this study is that EFP must use models of MY2001-era vehicles to represent the mix of collision partners in the year 2018. Because of the enormous expense of building new FE models, there is little else that the study could do other than use existing models of MY2001-era cars. However, the report should consider stressing this limitation to readers who are assessing the societal injury risk associated with light-weighting vehicles.

Likewise, the set of statistical distributions computed from 1985-2010 NASS/CDS may also be substantially different than will be observed in NASS/CDS 2018. New technologies, e.g. automatic emergency braking, for example could produce radically different impact speed distributions in future fleets. Likewise, as Lane Departure Warning and automated lane-keeping systems are more widely deployed, we can expect a much lower incidence of single vehicle, road departure crashes into fixed objects, e.g. poles. Prediction of these future collision distributions was not the goal of EFP, but should be pointed out to readers and policymakers who are evaluating the effect of light-weighting vehicles.

Additional Comments

n/a

IV. Combining individual occupant injury risk into overall injury risk for the fleet

Please discuss the suitability of the methods used to combine the occupant injury risk for the individual crashes into the overall occupant injury risk. Please note any omissions or overstatements.

The combination of systems modeling with detailed FE models of proposed future lightweight vehicle designs is a major plus of this project and engineering approach. It allows fleetwide evaluation of crashworthiness long before construction of physical prototypes. Systems Modeling permits crashworthiness evaluation across the full range of crash conditions that a vehicle is likely to experience if it were implemented on U.S. highways, and evaluation of occupant protection across the full spectrum of drivers likely to operate the vehicle.

A crucial component of the EFP is its consideration of not only protection of its own occupants (self-protection), but also the study's consideration of the injury risk to its collision partners (partner-protection). Traditional crash tests, e.g. NHTSA full frontal NCAP crash test, only consider the protection of the subject vehicle occupants. However, the unintended consequence of this approach is that vehicle designs which protect the subject vehicle's occupants may do so at the expense of their collision partners. EFP is a far superior method as it considers the injury risk to all persons involved in a crash with the target vehicle.

With all due respect, my biggest criticism of the report is that it is overly modeling-centric. The over-arching goal of this study is to determine the effect of new designs upon 'Societal Injury Risk' (SIR), and it was less than ideal that the reader must wait until page 49 in the report to see an explanation of what is meant by this key concept. Because the primary objective of this study is to determine fleetwide safety benefits, a description of the metric by which fleet benefits will be judged should be introduced early in the report. I recommend moving this entire section (section 3.7.4) to the beginning of Chapter 3 rather than leaving it to the end.

The study would greatly benefit by a more thorough definition of what is meant by 'Societal Injury Risk'. The equations in section 3.7.4.1 should be clarified to more precisely define SIR. My assumption is that SIR is a probability, but it was unclear either from the text or the equations what target population the probability pertained to. Is the target population all occupants, all drivers, all drivers in frontal crashes or all drivers in towaway crashes? Because the crash statistics presented were from NASS, my interpretation in reading section 3.7.4.1 was that SIR was the probability of MAIS3+ injury in all drivers in frontal crashes. However, I became less certain after reading section 3.8.3 in which the study reported using GES (police reported as opposed to towaway crashes) for some of the weights.

It would be helpful to remind the reader in the lead paragraph of section 3.7.4 of how the study categorizes injury versus non-injury. A precise definition of injury is critical in order to understand later statements on injury. For example, the paper states that 0-11 mph crashes were not simulated because no injury was expected. However, these low speed crashes could certainly produce MAIS1 injuries, but in this study, my read is that MAIS1 or MAIS2 occupants would be considered uninjured. The approach of this study was to base SIR on the risk of serious injury (MAIS3+) rather than a risk of any injury. Is this correct?

Please define what is meant by 'Exposure Rate'. Is this in units of drivers, drivers/year, or a frequency? It appears from section 3.8.1 that exposure rate is a frequency. If so, the term 'Exposure Rate' should be reworded as a frequency is not a rate. My read of these equations is that exposure rate appears to be a conditional probability. Rather than "Exposure Rate for Full Frontal, SUV" a better, more conventional wording would be "Probability of Full Frontal Crash involving a SUV"

Please define what is meant by 'Weighting Factor'. Are the units in terms of drivers, drivers/year, or a frequency? Are the weighting factors absolute numbers (as used in some studies) or probabilities (as used in other studies)?

Section 3.7.4.1 should cite the source (Laituri) for the 0.75/0.25 split between mid-sized males and small statured females. This is explained later in the report, but the 0.75/0.25 constants were used in the equations in 3.7.4.1 without explanation and made the equation difficult to interpret. Alternatively, the report could simply replace the 0.75/0.25 constants with variables and then give the specific values from Laituri later in the report.

In Table 3-32 and Table 3-33 (page 57), the report uses NASS/GES to define the distribution of two vehicle crash types, e.g. car-to-car, or light truck to light truck. Please provide the rationale for the use of GES. All other parts of study have relied almost exclusively on NASS/CDS to estimate related distributions. GES and CDS samples use very different inclusion criterion (CDS is a sample of all towaway crashes while GES is a sample of all police-reported crashes). The report should discuss what bias switching from CDS to GES with their differing sampling strategies may introduce into the results.

The caption for Table 3-32 states that the data in this table was developed using crash distributions and registration data from 'Traffic Safety Facts'. It would be useful to provide additional detail on how registration data was used to compute this table.

Table 3-32 and Table 3-33 present crash pairings from the GES analysis which appears to contain all crash modes (frontal, side, rear, etc.). The EFP study however focuses entirely on frontal crashes. My concern is these GES distributions may not be applicable to the target of frontal crashes which the study is examining. The study should consider either restricting Table 3-32 and Table 3-33 to frontal crashes only, or alternatively showing that there is no statistical difference between the crash pairing for all crashes and frontal-only crashes.

The paper states "For the car class, a 50/50 distribution of PCs <3000 lbs. and PCs >3000 lbs. and a 50/50 distribution for SUVs and Pickups in the Light Truck (LT) Class are assumed, shown in Table 3-33." What is the basis for making this assumption? This exact distribution can be readily computed from either NASS/CDS or NASS/GES. The paper would benefit from using the actual distribution in the study of fleet benefits rather than using this assumed distribution.

<u>Given the assumptions in the vehicle models, fleet representation, crash configurations, and generic occupant interior models, please discuss the suitability of the results for forecasting future safety issues.</u>

One limitation of the study is that the analysis is limited to consideration of drivers of age 16 to 50 years of age. Older drivers are at substantially higher risk of injury in crashes than drivers in this younger age range. The reports points out this limitation and states "It has been shown that adult occupant injury tolerance decreases with age and the elderly group has a higher risk of injury than the younger age group at any given crash delta-V…. This requires different risk functions for elderly group which is not included in this phase of the project."

The study made this simplifying assumption in this first iteration of EFP. However, inclusion of the older driver group (> 50 years old) needs to be a priority improvement to the model. Designs which optimize younger driver safety (by for example stiffening the structure) may result in a substantial disbenefit for older, more frail drivers. The concern is that any benefit for younger drivers may be overwhelmed by the disbenefit for older drivers.

Additional Comments

The study would benefit by validating the fleetwide model predictions for the baseline vehicles against the actual real world injury counts tabulated in NASS/CDS. Specifically, the study should compare the actual risk as measured by NASS/CDS for each of the 3 baseline vehicles (Taurus BL, Accord BL, and Venza BL) against the societal risk predicted by EFP for these baseline vehicles. NASS/CDS contains the number of MAIS3+ drivers for each baseline vehicle in exactly the same configurations for which EFP simulations were conducted.

V. Other Potential Areas for Comment

Is the methodology used reasonable? Is the study valuable to understand the safety implications for 2017-2025 mass-reduced vehicles light-duty vehicles? Please explain why or why not.

As noted earlier in this letter report, Systems Modeling is a superior method to traditional techniques, e.g. crash testing, for evaluating the crashworthiness of existing or proposed vehicle designs. The Systems Modeling methodology, presented in this report, evaluates vehicle crashworthiness across the full spectrum of crash modes, collision partners and potential drivers which a vehicle is likely to experience on U.S. highways. The result is a much more robust of societal injury risk than can ever hope to be provided by a small number of crash tests.

Do the study design concepts have critical deficiencies in its applicability for 2017-2025 timeframe? If so, please describe.

I interpreted this study as a pilot or feasibility study of Systems Modeling. Although the analysis described in the subject report is very comprehensive, it is important to point out that the study considers only a subset of potential frontal crashes and is applied to a select subset of drivers. Not considered are drivers over age 50, an age group particularly vulnerable to crash injury. Likewise, the study does not model frontal-side crashes in which the lightweighted vehicle strikes a collision partner in the side. Not considered in this pilot study are the tradeoffs between making a lightweight vehicle stiffer for better frontal occupant protection and the potential side effect that stiffer, lightweight vehicles are likely to be more aggressive or incompatible with their side struck collision partners. Also, not considered by the model is the injury risk for unbelted occupants. In the U.S., only about 15% of occupants are unbelted, but this small fraction accounts for approximately 50% of all fatalities.

I want to emphasize again that the authors have done a superb job in assembling the Systems Model. But the results of this pilot study should be used with caution in drawing any immediate policy conclusions as the issue of older drivers and side crash compatibility remains to be evaluated. Follow-on improvements to EFP, many of which were outlined in the subject report, should be actively pursued to obtain an improved fleetwide assessment of societal injury risk.

Additional Comments

n/a

Please provide any comments not characterized in the tables above.

The following are suggested minor editorial corrections for the report:

1. Spell out all acronyms, e.g. CARB, EPA, BL, LW, etc. These acronyms are defined in the report, but the executive summary should be stand-alone.

2. The equation in Figure 1 shows that risk is computed as summing over all occupant locations in each car. However, this study only considers drivers. The summation over all occupants is unneeded.

3. The indices in the weights in the equation in Figure 1 and the following paragraph are inconsistent. The weights in Figure 1 are specified as $W_{jklmnop}$ while the weights in paragraph following this paragraph are listed as Wi_{jklmn} and later in this paragraph as $Wi_{jklmnop}$.

4. On p.3 of this chapter, the report states that it was Volpe in 2000 which first used AIS to score injury severity. The report should be corrected to show that the University of Virginia included AIS in their revisions to the SSOM model in the early 1980s. The report should consider citing the following as a reference for this:

   White KP, Pilkey WD, Gabler HC, and Hollowell WT, "Simulation optimization of the crashworthiness of a passenger vehicle in frontal collisions using response surface methodology," SAE Paper 850512, SAE Transactions, Journal of Passenger Cars, Section
   6, (1985)

5. Figure 3-1 shows that Fleet FE and Target FE models were used as input to the EFP model. But FE models were only used for the vehicle structure. Madymo models were used for the occupant interior. Consider changing the labels in this figure to show "Fleet FE and Madymo Models" and "Target FE and Madymo Models"

6. Table 3-4 shows weighted values of frontal crash involvement and serious injury. It is not possible from this table however to judge what sample size these values are based. It would be beneficial to provide a table like Table 3-4 with unweighted values.

7. Table 3-12, Table 3-13, Table 3-14 and Table 3-15 should provide units of measure.

8. Figure 3-9 provides an equation for 'Accumulated Injury Risk' without defining what this is. I assume that this is the same as 'Societal Injury Risk' (SIR) or total risk presented elsewhere in the report.

9. The equation in Figure 3-9 for total risk is not consistent with the equation for total risk presented in Figure 1 or the equation for SIR presented in Section 3.74.

10. On Table 3-32, the note “HT are heavy (10,00lbs)” appears to have a missing zero.

11. In Table 3-33, the table heading has a misspelling. ‘paring’ should be ‘pairing’.

12. In the caption for Table 3-22, the term SRI should be replaced with SIR.

13. In Section 3.7.4.1, should ‘Societal Risk’ be labeled as ‘Societal Injury Risk’?

6.0 PEER REVIEW COMMENTS FROM DR. MUKUL VERMA

Review of

"Methodology for Evaluating Fleet Protection

of New Vehicle Designs- *Application to Lightweight Vehicle Designs*"

Reviewed by: Mukul K. Verma

<u>Overall Comments on:</u>

<u>The Topic</u>: This research area is of high importance. Macro-level models that estimate the socioeconomic effects of regulated and unregulated automotive design requirements on fleet-wide traffic safety are necessary to ensure that future decisions are based on overall benefits and they avoid unwanted 'side effects' from individual, isolated steps.

<u>The Report</u>: The reviewed report (referred to as 'NCAC study') is an innovative and important step forward in developing models of the effects of automobile mass reduction on front impact safety of the entire fleet. The study utilizes statistical analyses of frontal crashes in NASS CDS to select 'representative' configurations and employs CAE-based simulations of vehicles and occupants to estimate the effect of mass reduction of vehicles on drivers' injuries. These are then summed with assigned weights to obtain fleet-wide estimates for frontal impact safety. This methodology has the potential to provide useful information if further work is done to address the deficiencies identified in the NCAC study and in the comments below.

<u>The Numerical Estimates:</u> Numerical estimates in the above-mentioned study are based on assumptions and CAE models which require significant improvements and verification in order to make the results usable and reliable projections of injury harm to vehicle drivers in the current or future fleet. Also, the range of simulated crashes needs to be expanded to include the crash speeds observed in large numbers of frontal impacts in the existing databases.

This is valuable research and it needs to be continued.

<u>DETAILED REVIEW</u>

My background for this review: As a peer reviewer of the earlier NHTSA study on lightweight design of the Accord, I had evaluated the baseline and the lightweight variants of that vehicle in detail. This included obtaining from NHTSA and executing the finite-element simulations (LS-DYNA) of these vehicles. I had suggested some changes in the front structure design of the LW variant so as to make its airbag deployment comparable to the baseline Accord. I am not sure if those structural changes were incorporated in the model before these were used for the current NCAC study.

I have also utilized several of the finite-element models developed by NCAC (including the Taurus and the Silverado) on many occasions for my research projects. I am familiar with the EPA/ Lotus Engineering study but I have not executed any finite-element models of Yaris or Venza.

My professional experience with two different companies has been in engineering and testing of production vehicles to meet safety criteria and in utilizing CAE & FEM based simulation techniques to achieve these goals.

(1) Vehicle Structural Models:

a. *Please comment on the suitability and accuracy of the baseline and lightweight FEA models for use in the range of frontal crashes in this study. Also please consider the accelerations and intrusion outputs that were used to drive the occupant simulations.*

The methodology of nonlinear finite-element analysis utilizing LS-DYNA is widely used for simulating crash response of automobiles. Various degrees of usability and confidence in these models have been achieved by the users. Such a model (or any simulation) has the ability to be usable and reliable representation of the automobile's impact response in only a limited range of simulation conditions and only for some response variables. This range of applicability depends on the level of detail in the model, degree of verification and validation, type and severity of crash, etc. The degree of confidence needed in a particular model is determined by the intended use. A model used to guide the physical design of an automobile going into mass production requires much more detail and verification than models for simpler investigations of trends from variation of a few parameters. The important factors in assessing the fidelity of vehicle models are (a) the level of physical detail in the model, (b) the rigor in defining material properties, and (c) the inherent assumptions and simplifications. Many of the finite element models used by automobile manufacturers are large (several million elements), include material properties derived from extensive laboratory tests of components and are verified on multiple occasions.

In the present case, the ultimate task is of developing fleet-wide models whose outcome will affect transportation and energy policies of the nation. Such models require a high degree of confidence and verification. As stated on p.5 of the NCAC study, "The results of EFP depend(s) on the credibility of these FE models".

The currently existing FEMs of automobiles were primarily developed for simulating high speed crashes in NCAP and IIHS tests (35 mph frontal impacts, 40 mph offset deformable barrier impacts, etc) which have been an area of competition for automobile manufacturers and where these simulations helped make decisions with fewer tests and in shorter time. Since the automobile is a complex nonlinear system consisting of multiple mechanical/ electrical/ electronic/ hydraulic components, its representation by digital model requires many assumptions and simplifications because not all dynamic events and material behavior can be fully represented mathematically. Therefore, it can be expected that a digital model will be a reasonably reliable representation of the vehicle performance in events which are close to those used in developing the model. It can also be expected (similar to Taylor's theorem) that an FEM (or any approximation) will become less reliable further away from the parameters that were used in establishing it ('range of validity'). The usual practice for establishing the range and the degree of validity in any model-based approach is to conduct well-controlled tests and to compare the results to the simulations. These tests need to be conducted at speeds and other conditions close to those being simulated.

The NCAC study shows some experimental validation for the high-speed crashes but does not provide any data to quantify the validity of the models at lower impact speeds (15 mph, 20mph). The two comparisons for 25 mph impact show that the FEM results differ greatly from the test data. In Appendix A-7, figure 20 shows the Accord crash pulse comparisons at 25 mph with large differences between the FEM data (20g peak) and that from a test (32 g peak). Similar conclusion regarding large differences between the FEM-estimated and test-measured structural response (43g versus 26g) are seen for Yaris (Appendix 9, figure 11).

This illustrates the need to improve the models for lower speed impacts so that they can be used reliably as surrogates of physical crashes at the speeds observed in the field. Since the lower-speed impacts constitute most of the crashes in the US fleet (NASS CDS data, p.52 of NCAC report), it takes on added importance that the models for these crash conditions have acceptable levels of numerical verification and validation.

Another area of concern in the NCAC study is the lack of test data to verify the accuracy of of vehicle-to-vehicle crash simulations.

As a rule, it cannot be assumed that any digital model will represent all possible crash scenarios and all possible response parameters with any degree of reliability unless it has been explicitly verified to be so.

b. *Please comment on the suitability and accuracy of the four FEA models used to represent the crash partners for use in the range of frontal crashes in this study. Comment on their suitability to represent the general behavior of vehicles in their class.*

Since the four vehicles (Yaris, Taurus, Explorer, Silverado) range in weight from 1100 kg to 2270 kg and usually sell in large volumes, their selection to represent the US fleet is an acceptable approximation. For future studies, it may be worthwhile to use recent vehicle models (Taurus model in the NCAC study is of 2001 MY vintage).

However, the selection of target vehicles, namely the Taurus variants LW3 and LW4, raises questions. These two variants are stated as (a) '25% lighter' and (b) 'overall stiffer'. But no design or performance evaluations are given nor is it stated that these two variants were based on any set of criteria for 'feasible' automobiles. No data are shown about these variants meeting any set of performance and manufacturing criteria for the 2017-2025 timeframe. As is the case for large, complex systems, there are multiple ways to get a 25% mass reduction and/or overall stiffness increase in a vehicle that is not constrained by engineering or manufacturing criteria. However, not all of these ways will represent a 'likely' vehicle in the current and future US fleet (or 'real word' in the report's terminology). It is therefore unclear why the Taurus variants were considered to be part this study regarding the future fleet.

Additionally, it should be remarked that these two variants are shown (p. xiii, p.61) to be the largest contributors to the societal risk increase in all three formulations. More data or citation is needed to explain this selection.

c. *General Observations:*

As mentioned above, it is important that vehicles selected as representing the fleet, whether the current fleet or the projections for 2017-2025 timeframe, be 'feasible' in the sense that they be demonstrated as meeting a consistent set of performance/manufacturing/cost criteria in the expected timeframe. Once a set of 'feasible' vehicles representing the fleet are selected, the next requirement is that the finite element models of these vehicles be demonstrated to have sufficient degree of correlation to physical tests (or 'real word' data, in the report's terminology). As stated earlier, such correlation is missing for most of models in the present NCAC study.

It is recommended that the statement 1 (section 5.2.2, p. 95) be revised to reflect the limited applicability of nonlinear finite element analysis method and the immediate need for several improvements. As is correctly shown at several places in the report and in the appendices, there can be large differences between the simulated and the measured (in a test) structural responses at the present state of knowledge of FEM. The report's statement should be revised to reflect that since most (or almost all?) of accidents in the field appear to be below the 35 mph test speed, it is necessary to improve the fidelity of the structural models for these lower impact speeds.

(2) Occupant Kinematics Models:

(a) *Please comment on the suitability and accuracy of the occupant kinematic models used in this study.*

The NCAC study uses decoupled simulation of the occupant's kinematics, using MADYMO software in frontal crash modes. Given the constraints of time and cost, it is a sensible approach and has been used by many researchers. In the present case, a large number of simulations were made to obtain the results for a 50th percentile male ATD and a 5th percentile female ATD in the various frontal crash scenarios. Although I have not checked the individual runs, the results shown indicate proper application.

Without using a finite-element model of ATD, MADYMO represents the body segments of an ATD by simple geometrical shapes intended to represent the contact forces generated in impacts but not necessarily in terms of details of a segment's physical shape. Since this involves a high level of approximation (i.e. many physical parameters are ignored), its usefulness is generally confined to a narrower range where a degree of confidence in the model has been established by comparison with test data. This technique (of decoupled simulation with MADYMO) is often used to investigate 'trends' from small changes in the restraint system (seatbelts, airbags, knee bolster) parameters that do not affect the occupant's trajectory to significant degree. In cases where the restraint system design is stable, this method is also used to investigate the desired changes in vehicle structural response to improve measures of occupants' impact severity.

There are several challenges in creating usable MADYMO models to guide physical design of an automobile's interior components and its restraint systems. One of these challenges is in adequately simulating the seat-to-lower body and the foot-to-floor interactions. Dynamic behavior of the seat structure, seat pan and seat foam are more complex than behavior of metallic components and may not be well-represented by existing material models outside a narrow range of loading and deformation. The construction of the ATD lower body segment, which includes non-metal parts, also necessitates many approximations in creating simulations. These factors often are the reason behind difficulties in matching the initial and the dynamic positions of the ATD to that observed in physical tests.

Since the initial position and interactions of the lower body parts determine to a significant degree the knee-to-IP loading (which dissipates most or much of the ATD's kinetic energy), it becomes important that reliable representations of ATD-to-seat and ATD-to-floor interactions be developed. In the NCAC study, the latter is simulated to various and differing (from vehicle to vehicle) levels of detail including addition of a 'foot stop' (p.33) to some models to obtain results closer to the test data.

Another challenge of MADYMO methodology is in reliably simulating the neck and the head response when impacted by airbags, specially for the 5th percentile ATD. The head deceleration and the neck forces and moments are determined by the dynamic interaction between the airbag and the occupant's head and upper torso. A decoupled MADYMO model is useful for providing trends and for obtaining 'design directions' but may not reliably predict the absolute measures of ATD's injury measures, specially for the smaller occupant.

(b) *Please discuss the suitability of the restraint systems and firing times in the occupant kinematic models. Also comment upon the occupant injury measures considered in this study.*

The simulations of the seatbelt-to-occupant and airbag-to-occupant interactions are of critical importance in using MADYMO to analyze occupant kinematics in crashes. These capabilities have undergone long periods of development in MADYMO and the overall kinematics of restrained occupants are generally well represented if the seatbelt properties including pretensioners, load limiters, etc. are close representations of the physical behavior of these systems as observed in crashes. On the hardware side, seatbelts are developed for each specific vehicle and undergo extensive amounts of testing and refinement in order to minimize the impact severity experienced by the occupants.

The restraint systems used in the NCAC study are stated as being 'generic' and not obtained from the vehicles or their manufacturers. Thus, the seatbelts and airbags likely differ significantly from those in actual production vehicles. Although the NCAC study states that this generic system was 'fine tuned' to match results from some high speed tests, such a forced match at one point in a domain may not denote any degree of fidelity ('real world' representation) in all the crashes. This introduces additional uncertainty in interpreting the results of this study.

It is stated in the report that the firing time for each vehicle's airbag was estimated from belt load time history of the NCAP tests and 'rules' were established for estimating the firing time at other impact speeds. It is not stated if in each case, the airbag was inserted into the MADYMO model at this estimated firing time and if in each case, it was simulated as fully deployed at a certain time interval prior to impact by the ATD. The shape and dimensions of the airbags in production vehicles are developed after many iterations and are designed to optimize protection. However, these are not used in the NCAC study. The use of generic airbag without any comparison to the physical designs in the vehicles makes it difficult to assess how these results represent physical crashes. Some degree of confidence could be established by comparing the ATD responses (trajectories, impact severities) between the MADYMO simulation and the tests at each speed.

As a suggestion, the distinction between 'firing time' and 'instant of impact' or 'time at which fully deployed' should be clarified.

An occupant restrained by seatbelts in a frontal crash exerts large forces on the seat and on the lower instrument panel. As stated earlier, the resulting deformation of seat depends on several factors, including the shape of the contact area with the occupant, the non-uniform and nonlinear force-versus-deflection properties of the ATD and the seat. Since the simulations of this in MADYMO require many simplifications and approximations, it is necessary to establish a degree of confidence in each specific event simulation by comparison with tests conducted at or near the same test speed with the same ATD and restraint system (stated on p 27, *" .. before the occupant simulation matrix could be executed, it was necessary to validate each occupant model to actual crash test data to make sure the estimated injury risks are realistic and the injuries are as close as possible to real world injuries"*). The NCAC study does not show numerical verifications of occupants' kinematics at 15, 20, 25 mph speeds of impact.

(c) *If you are aware of other methods to predict occupant injury risk, please suggest why you think they would improve this study and how they might be used.*

There are commercially available finite element models of ATDs and there also exist simulation capabilities to combine the vehicle and the occupants together in the same LS-DYNA model. While these combined simulations take longer to run than the decoupled MADYMO models, they have the additional capability of representing the interactions between the vehicle and the occupant (ATD) to a larger degree than decoupled models. Such combined simulations are necessary in most cases for better estimate of impact severities.

However, in all cases, it is essential that the models and its approximations be verified by crash tests conducted close to the simulated impacts.

(3) Crash configurations and mapping to real world risk of injury

a. *Please comment on the selection of the vehicle-to-vehicle and vehicle-to-fixed object crash modes selected, the range of impacts speeds and their suitability for evaluating future crash safety.*

The frontal crash parameters selected for this study from analysis of NASS CDS database appear to represent a sufficiently wide range of frontal crashes (except crash speeds, as discussed below). Similarly, the selection of 'full engagement' and '50% offset' crash modes for vehicle-to-vehicle crashes represent the configurations likely to 'bound' the existing data and are therefore an acceptable range (of this parameter) for initial estimates of trends.

The major question in regards to the results from NCAC study is in the selected crash speeds for single vehicle crashes as well as for vehicle-to-vehicle crashes. The NCAC study selections are biased towards higher speeds of crashes which are fewer in number as shown by the NASS CDS data. In order to properly represent the current fleet-wide observations (p. 54-55) , it is necessary to include barrier equivalent speeds of 0-11 mph which predominate in the field events. This (inclusion of 0-11 mph crashes) may change the study's numerical outcome because the relatively large numbers of these mph crashes may significantly affect the weighted sums.

It should be noted that for some vehicles, this speed range may be a boundary between airbag deployment and non-deployment decisions. This has implications for simulation of the ATD response.

b. *Please comment on the methods used to relate the individual crash simulations to their real world frequency of occurrence.*

The NCAC study states that the front crash parameters in the NCAC are obtained by analyzing NASS CDS data for identifying such parameters and all the frontal crash modes are then represented by three types of crashes. Although not stated, the reason for selecting these types appears to be that many crash tests have been conducted of these types and are available in the literature. The three types utilized in the study are- full frontal impact with a rigid barrier, an offset crash with deformable barrier and a vehicle-to-rigid pole impact. This selection has the advantage of utilizing existing knowledge (and existing levels of familiarity and confidence) of these models and is therefore a suitable step for developing the methodology and for 'preliminary' estimate of feasibility. However, as stated earlier, the crashes observed in the field are mostly at lower speeds and are different from NCAP and the IIHS ODB tests in many respects. Therefore, it is recommended above to modify crash configurations and simulated speeds to better represent the observed data.

Some information also needs to be provided to explain the selection of vehicle-to-pole impact as a surrogate for 'front impacts between rails'.

c. *Please recommend other methods or improvements to map the crash simulations to real world occupant safety risk.*

Several such suggestions have been made in the paragraphs above. These are related to using verified/validated models and more representative crash configurations for creating FEM-based simulations.

The high speed impact simulations, where the study's verification and validation efforts have been concentrated, represent 'extreme' crash configurations that are a very small fraction of field events. More work needs to be done to improve the LS-DYNA and the MADYMO modeling methodologies to make them representative at the more common, lower speed crashes.

The next step in creating macro-level models of fleet-wide automotive safety is to introduce probability estimates in the FEM formulations. This concept has been discussed in the past and the existing computation capabilities are capable of handling such simulations.

(4) Combining individual occupant injury risk into overall injury risk for the fleet

a. *Please discuss the suitability of the methods used to combine the occupant injury risk for the individual crashes into the overall occupant injury risk. Please note any omissions or overstatements*.

In the report, the calculation of combined injury risks for the entire fleet is based on a weighted sum of injury risk from individual crashes. This assumes the injury risks to be a linear function and ignores the second-order terms. Generally, this provides a 'lower bound' of the overall sum and this approach is widely used in estimating domain-wide results and creating 'first estimates'.

In addition, the study assumes that the population is adequately represented by the 50th percentile male ATD and the 5th percentile female ATD. This is a major assumptions and the reason for it appears to be that these are the only two sizes of ATDs currently available and in wide use for front impact testing. This assumption needs further testing.

The NCAC study does not include considerations of the effects of age on the risk of injuries. This aspect should be investigated further since the projected US population for the 2025 timeframe is likely to be older and the distribution different from today's population pyramid.

b. *Given the assumptions in the vehicle models, fleet representation, crash configurations, and generic occupant interior models, please discuss the suitability of the results for forecasting future safety issues.*

The methodology in this study is an important step forward in demonstrating feasibility of the approach but the numerical results of this study cannot yet be considered to be 'real world' estimates of the effects of automobile mass reduction on front impact safety. There are multiple reasons for this opinion:

- the crashes simulated in the study do not represent the full spectrum of frontal crashes,

- little or no verification is provided for vehicle & occupant models at 15,20, 25 mph which constitute most of the frontal crashes,

-the models of the driver' kinematics are not based on actual seatbelts and airbags used in the vehicles,

-the many simplifying assumptions in seat and floor models are not verified for adequacy and applicability,

- two of the partner vehicle designs contribute heavily to the overall numerical results but are not shown to be viable or feasible vehicles for the 2017-2025 fleet,

- the report's authors point to several difficulties and issues/inconsistencies in the findings (p.84, p.82, p.86, p.89, p.90) and these need to be addressed before the study's results can be used in product- or policy-related decisions.

Many of the above points relate to the current state of knowledge in finite element simulations of vehicle-to-object and of occupant-to-vehicle interior impacts. These could be addressed by additional research work supported by a limited number of tests at points of high sensitivity.

(5) OTHER POTENTIAL AREAS FOR COMMENT

a. *Is the methodology used reasonable? Is the study valuable to understand the safety implications for 2017-2025 mass-reduced vehicles light-duty vehicles? Please explain why or why not.*

The methodology used in NCAC study is innovative and as such, the study is of significant value in illustrating the viability of the concept. It is also valuable because it clearly identifies the shortcomings and the need for additional research. However, the numerical findings of this study do not yet provide a reliable forecast of the effects of automotive mass reduction for the 2017-2025 fleet.

b. Do the study design concepts have critical deficiencies in its applicability for 2017-2025 timeframe? If so, please describe.

The current NCAC study should be considered one significant step in developing methodologies to evaluate relationship between overall (fleet-wide) safety) and mass reduction of automobiles. More steps are necessary and the underlying technologies (simulations) need to be improved before the answers are of value. Most importantly, other crash modes and occupant sizes/age may need to be added to the model to make it fleet-representative. It is also essential that all other crash modes (lateral, rollover, etc) be included along with the frontal impacts in making any projections. As is well known, changes in vehicle design can have different effects in different crash modes.

It is a concern that the numerical results of the present study, although based only on frontal impact simulations of limited capability may be misinterpreted by some as supporting the opinion that 'less mass means less safety'. Such opinion will be premature and may not be technically justified.

SUMMARY

The NCAC study develops an innovative approach for creating fleet-wide models of effects of design changes in automobiles by combining by synthesizing several methodologies. The results provided therein for frontal impacts show the feasibility of this methodology. The numerical conclusions of the present report do not yet reliably represent fleet-wide effects due to several reasons discussed above.

The research project needs to be continued and more work needs to be done in order to improve the capabilities and generate usable data.

7.0 GWU RESPONSE TO PEER REVIEW COMMENTS

NCAC
THE NATIONAL CRASH ANALYSIS CENTER

Peer Review Comments Log for the report:

Methodology for Evaluating Fleet Protection of New Vehicle Designs: Application to Lightweight Vehicle Designs

November 2013

Authors: Randa Radwan Samaha, Priya Prasad

George Washington University, Prasad Engineering, LLC.

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THE GEORGE WASHINGTON UNIVERSITY
WASHINGTON DC

Peer Review Comments Log

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
1	Fischer	4	Vehicle Structural Models: SUV's and light trucks are a large portion of the vehicle fleet and to not have a truck as one of the target vehicles may limit the overall effects of lighter vehicles. Light trucks are inherently heavier and potentially have more of an opportunity to reduce weight.	3.4	No response required.	No change.
2	Fischer	4	Vehicle Structural Models: The accelerations and intrusions from the FE models seemed reasonable. It would be good to see the comparison to actual data (NCAP, IIHS, etc.) to demonstrate a level of correlation.	A-2 A-3 A-4 A-5	For tests where intrusion data were available, the comparisons for the validations simulations are included in the vehicle FE model development appendices.	Please see A-2 A-3 A-4 A-5
3	Fischer	4	Vehicle Structural Models: The four vehicles selected did cover the wide range of vehicle sizes from large to small. The Silverado and Explorer are top 20 sales volume vehicles. However, the Taurus and Yaris are not quite as high. A higher volume mid-size car and small car would represent more cars in the fleet.	3.3.2	The best FE models available at the time were used. In the future, additional segments of the fleet will be considered pending availability and funding. FE models of newer and higher volume mid-size car and small car in the fleet will also be considered as those become available.	3.3.2 and 6.1.3
4	Fischer	5	Occupant Kinematic Models: MADYMO is a proven tool for evaluating occupant kinematics and loads. It can easily simulate the restraints and the occupant interactions. Plus, run times are relatively short.	3.5.1	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
5	Fischer	5	Occupant Kinematic Models: There was some discussion on the restraint characteristics. However, a more complete summary of the restraint systems for all the vehicles would establish the technology level. Restraints are continuously evolving and summarizing them would 'put a stake in the ground' for this study. Some of the key characteristics would be number of inflator stages, bag volume, venting and tethers, seat belt pre-tensioning and energy management level. If dual stage inflators were used, at what crash conditions were the low output levels used.	3.5.2	A table was added to the report to summarize the airbag and seat belt characteristics for the lightweight vehicle models.	Table 3-11
6	Fischer	5	Occupant Kinematic Models: Using the '5-30 rule' is a logical starting point when no actual algorithm was available. It was interesting to see how the 5-30 rule matched known tests.	3.5.2.3	No response required.	No change.
7	Fischer	5	Occupant Kinematic Models: The occupant injury measures chosen have a good correlation to estimating injury potential. It is curious why Nij wasn't included nor discussed why it wasn't included. It is commonly used in FMVSS 208 and NCAP.	3.7	The Normalized Neck Injury Criterion (Nij) used in the 2011 NCAP was initially considered for the neck body region. However, since the corresponding AIS3+ risk function for Nij has the threshold issue of computing a probability of 3.8% serious injury risk at Nij=0, the risk function for the neck tension was preferred for this study. Also, the NCAP risk function for neck tension has been shown to be a better predictor of serious neck injuries than Nij in the real world based on NASS CDS .	3.7.1
8	Fischer	6	Crash Configurations and Mapping to Real World Risk of Injury: The range of partner vehicles, fixed objects and relative speeds covered a wide range of crash conditions. They provided a good mix of known tested conditions (NCAP, IIHS, FMVSS 208) and more common vehicle-to-vehicle interactions.	3.6.1	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
9	Fischer	6	Crash Configurations and Mapping to Real World Risk of Injury: The NASS analysis break down helped verify the majority of crash conditions were covered in the simulations. A small overlap crash would have nice to include since it is becoming a hot topic, but it is understandable that the FE models may not have the robustness to predict such a crash.	3.2	Simulation of a small overlap crash will be considered for future studies; however the FE models will need be further developed and validated to model complex interaction in small overlap impacts.	No change.
10	Fischer	6	Crash Configurations and Mapping to Real World Risk of Injury: It is understandable to start with the frontal crashes, but in the future it would make sense to look at side impacts. Similar to what was demonstrated in this study, it is expected that the door intrusions in a side impact could increase and potentially increase injury risk.	3.2	This study was aimed at determining if the current fleet modeling process would lead to predictions of societal risks that are close to those observed in the current fleet, and if effects of design changes to a baseline vehicle can be detected. By constraints of time and model availabilities, this study concentrated on only frontal impacts and was a "proof-of-concept." We believe that the concept has been proven out in terms of the model predicting the real world experience and its sensitivity to vehicle design changes for frontal impacts. We have to keep in mind that frontal impact is the most important crash mode in frequency of occurrence and incidence of serious to fatal injuries. As noted in section 6, with further development, the EFP methodology can be applied to side and rear impacts.	6
11	Fischer	6	Crash Configurations and Mapping to Real World Risk of Injury: I think this section is the strength of the study. The mapping of NASS data and the parallel created in the simulation study is thorough and well thought out.	General	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
12	Fischer	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The path from the simulated crash conditions to the overall injury risk was well thought out and complete. If anything, there may be a slight overstatement due to the fact that the restraints weren't tuned. It was good this was noted in the discussion, but restraint systems are continuously evolving in improving. It is not out of the realm that restraints could reduce those injury risks in lighter vehicles.	4	The study was not designed to evaluate how restraint might change in response to light weighting. Using the same restraint system for the baseline and modified vehicles will help in in gaining insight on how the system needs to be changed. This was intentional and not the focus of the initial development of the methodology.	4.1
13	Fischer	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: As far as what was discussed in the study, it demonstrated the potential increased injury risk. However, as stated above the restraints are changing and other technologies are becoming more popular in vehicles like lane departure warning, forward collision warning, adaptive cruise control and automatic braking. These technologies could counteract some of the injury risk seen with the lighter vehicles.	4	See answer to 12 above. Text was added under section 4.1 to the effect that restraint technologies will be improved in the future, but for an initial analysis, this study gives a glimpse in the future of what will have to change to keep occupants safe.	4.1
14	Fischer	8	Other Comments: The path from the NASS data through the simulations to the final injury risks follows a logical path with reasonable assumptions. The assumptions always add a level of uncertainty, but in this case they are well explained and evaluated making them reasonable. As stated earlier, technologies today will be improved by the 2017-2025 time frame, but for an initial analysis this study gives a glimpse in the future of what will have to change to keep occupants safe.	General	No response required.	No change.
15	Fischer	8	Other Comments: Automotive technologies have changed for the past hundred years and will continue to do so. However, this study effectively evaluated potential areas where changes could be required to maintain the current level of occupant safety.	General	No response required.	No change.
16	Fischer	8	Other Comments: Page 7, paragraph 1, line 7: 'Figure 2-2' should be 'Figure 3-2'	3.2.1	The correction was made to the report.	3.2.1

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
17	Fischer	8	Other Comments: Page 8, paragraph 1, line 2: ‘Figure 2-4’ should be ‘Figure 3-4’	3.2.1	The correction was made to the report.	3.2.1
18	Fischer	8	Other Comments: Page 14, ‘PU (Pickup) Trucks…’ should be indented	3.2.3.1	The correction was made to the report.	3.2.3.1
19	Fischer	8	Other Comments: Page 29, paragraph 2, line 9: ‘… for Explorer …’ should be ‘… for the Explorer…’	3.5.2.1	The correction was made to the report.	3.5.2.1
20	Fischer	8	Other Comments: Table 3-12, 3-13, 3-14, and 3-15 should have units for mph and seconds.	3.5.2.3.1 3.5.2.3.3	Units added	3.5.2.3.1 3.5.2.3.3
21	Fischer	8	Other Comments: Table 3-18 should also have units.	3.7	The units are included in the row headers.	No change.
22	Fischer	8	Other Comments: Page 60, ‘Overall risk of the Taurus BL in SV is 0.15%=0.75x0.10 (not 0.15)…’	4.1	The correction was made to the report.	4.1
23	Verma	1	Overall Comments: Numerical estimates in the above-mentioned study are based on assumptions and CAE models which require significant improvements and verification in order to make the results usable and reliable projections of injury harm to vehicle drivers in the current or future fleet. Also, the range of simulated crashes needs to be expanded to include the crash speeds observed in large numbers of frontal impacts in the existing databases.		Crash velocities from 15 to 35 mph were simulated for full frontal and center pole impacts; same for offset crashes; we believe that we covered 98%+ of delta-v’s in NASS and over 90% of crash configurations. It is not possible to experimentally verify every structural or occupant simulation- too many. Both structural and occupant models were checked against NCAP, FMVSS208 (when available) and IIHS offset conditions.	No change.

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24	Verma	2-3	Vehicle Structural Models: The NCAC study shows some experimental validation for the high-speed crashes but does not provide any data to quantify the validity of the models at lower impact speeds (15 mph, 20mph). The two comparisons for 25 mph impact show that the FEM results differ greatly from the test data. In Appendix A-7, figure 20 shows the Accord crash pulse comparisons at 25 mph with large differences between the FEM data (20g peak) and that from a test (32 g peak). Similar conclusion regarding large differences between the FEM-estimated and test-measured structural response (43g versus 26g) are seen for Yaris (Appendix 9, figure 11). This illustrates the need to improve the models for lower speed impacts so that they can be used reliably as surrogates of physical crashes at the speeds observed in the field. Since the lower-speed impacts constitute most of the crashes in the US fleet (NASS CDS data, p.52 of NCAC report), it takes on added importance that the models for these crash conditions have acceptable levels of numerical verification and validation.	A-7 A-9	The Accord 25 mph test data represents a vehicle with a larger engine, hence reduced crush space led to a shorter duration crash pulse. This explanation has been added to the report. The difference in peak accelerations between the simulation and test of the Yaris is a correct observation. However the test acceleration is of a short duration and not expected to affect occupant responses. Full vehicle crash testing at other speeds or configurations were beyond the scope of this study.	A-7 page 11 A-9, no change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
25	Verma	3	Vehicle Structural Models: Another area of concern in the NCAC study is the lack of test data to verify the accuracy of vehicle-to-vehicle crash simulations.	General	Vehicle-to-vehicle crashes between Explorer and Taurus have been published by Barbat et al. [ref] in three different crash configurations- full frontal, offset and 30 degree angle impacts. The current models used for the two vehicles produce good comparison with the experimental data. There is no reason to believe that car-to-car simulations cannot be conducted with these models. We were somewhat restricted to use available FE models at the NCAC and the models of Accord, Venza and their derivatives that were developed under DOT/EPA/CARB funding. The derivatives were offered as concepts for reduced mass designs with advanced materials. Just as the model results were accepted by their sponsors at their face value for feasible light-weighted designs that also demonstrated safety at high speeds, we had to accept their crash responses at other velocities and crash configurations. General tests like energy conservation, hour-glassing and mass/time scaling have shown that most of the models were performing well in single vehicle and two-vehicle collisions. Obviously, it was impossible to validate the new designs with crash data as the vehicles do not exist. [Ref] Barbat, Saeed, Xiaowei Li, and Priya Prasad. "A comparative analysis of vehicle-to-vehicle and vehicle-to-rigid fixed barrier frontal impacts." In *17th International Technical Conference on the Enhanced Safety of Vehicles*. 2001	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
26	Verma	3	Vehicle Structural Models: As a rule, it cannot be assumed that any digital model will represent all possible crash scenarios and all possible response parameters with any degree of reliability unless it has been explicitly verified to be so.	General	We believe this to be a philosophical issue. Why run simulations if each crash condition has to be verified by a test? Also, we are using a single pair of vehicle crash configurations to represent response of all vehicle to vehicle crash categories. As such, the intended goal was to capture that trend and not specific vehicle responses.	No change.
27	Verma	3	Vehicle Structural Models: Since the four vehicles (Yaris, Taurus, Explorer, Silverado) range in weight from 1100 kg to 2270 kg and usually sell in large volumes, their selection to represent the US fleet is an acceptable approximation. For future studies, it may be worthwhile to use recent vehicle models (Taurus model in the NCAC study is of 2001 MY vintage).	3.3.2	Future studies could include more modern vehicle designs like the Accord or the Camry replacing the 2000 Taurus from the fleet, and potentially adding a unitized body SUV, such as Venza, into the fleet model. See response to comment 3. The results of a follow-up studies would shed some light on the robustness of the results of this initial study.	3.3.2 and 6.1.3

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
28	Verma	3	Vehicle Structural Models: However, the selection of target vehicles, namely the Taurus variants LW3 and LW4, raises questions. These two variants are stated as (a) '25% lighter' and (b) 'overall stiffer'. But no design or performance evaluations are given nor is it stated that these two variants were based on any set of criteria for 'feasible' automobiles. No data are shown about these variants meeting any set of performance and manufacturing criteria for the 2017-2025 timeframe. As is the case for large, complex systems, there are multiple ways to get a 25% mass reduction and/or overall stiffness increase in a vehicle that is not constrained by engineering or manufacturing criteria. However, not all of these ways will represent a 'likely' vehicle in the current and future US fleet (or 'real word' in the report's terminology). It is therefore unclear why the Taurus variants were considered to be part this study regarding the future fleet.	3.4.2	We were not looking for manufacturing feasibility- in fact we know that LW3 is not practical. We reduced the baseline mass by changing the density of the material. This gave us a virtual design where the original stiffness was retained with a lighter mass. The LW4 was similarly assumed to be composed of HSS maintaining the initial material gage. This gave us an opportunity to study the effect of increasing the stiffness without increasing mass. The two virtual vehicles help us isolate the effect of mass changes alone and stiffness changes alone. It is hard to predict how vehicles will be designed in the future. The trend of using lighter weight materials like Advanced High Strength Steels, Aluminum and Magnesium will continue and we expect the average mass of the fleet to be lighter than what it is today even if the “footprint” does not change appreciably. The distribution of vehicles in the fleet by their “footprint” might change based on consumer preference which is hard to predict. However, if future designs are known and CAE models of those designs are available, those vehicles can be inserted into the current field model to predict their safety effects in the future. Till then, we have to assume that drastic changes in vehicle architecture will not happen and design changes will be similar to the variants that we have studied, i.e. light weighted Accord and Venza. We believe that using the fleet model to predict the future is a better way than statistical predictions. Statistical predictions rely on trends that can be discerned from the past and any projections into the future assume that drastic changes in the design and demographics of the population will not take place. With our model, several “what-if” scenarios can be studied in a virtual environment.	No change.

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29	Verma	3	Vehicle Structural Models: Additionally, it should be remarked that these two variants are shown (p. xiii, p.61) to be the largest contributors to the societal risk increase in all three formulations. More data or citation is needed to explain this selection.	4.1	Results agree with previous empirical studies (Evans for mass reduction and Denise Woods study for mass reduction and increased stiffness). Not sure what is meant by "largest contributor to the societal risk?" In this study, we are not adding the societal risk increase/decrease for all variants, but estimating the effect of individual variant.	No change.
30	Verma	3	Vehicle Structural Models: As mentioned above, it is important that vehicles selected as representing the fleet, whether the current fleet or the projections for 2017-2025 timeframe, be 'feasible' in the sense that they be demonstrated as meeting a consistent set of performance/manufacturing/cost criteria in the expected timeframe. Once a set of 'feasible' vehicles representing the fleet are selected, the next requirement is that the finite element models of these vehicles be demonstrated to have sufficient degree of correlation to physical tests (or 'real word' data, in the report's terminology). As stated earlier, such correlation is missing for most of models in the present NCAC study.	3.4	The baseline models of Taurus, Accord and Venza yielded serious injury rates that were consistent with observed rates in NASS, in spite of all the simplifying assumptions of the fleet and its frontal crash experience in today's environment. The close predictions give us confidence that the methodology developed is robust. More vehicles and corresponding models would improve the accuracy of prediction, however in this study, the methodology is being tested. Note that the Accord and Venza lightweighted variants had undergone checks for manufacturing feasibility and cost criteria in agreement with their sponsors. One can then assume that these variants represented designs that could be representative of those in the 2017-2015 timeframe. This report was not aimed at evaluating the above factors.	No change.

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31	Verma	3	Vehicle Structural Models: It is recommended that the statement 1 (section 6.1.2) be revised to reflect the limited applicability of nonlinear finite element analysis method and the immediate need for several improvements. As is correctly shown at several places in the report and in the appendices, there can be large differences between the simulated and the measured (in a test) structural responses at the present state of knowledge of FEM. The report's statement should be revised to reflect that since most (or almost all?) of accidents in the field appear to be below the 35 mph test speed, it is necessary to improve the fidelity of the structural models for these lower impact speeds.	6.1.2	See answers to comments 23, 25, 26, and 30 above.	
32	Verma	4	Occupant Kinematics Models: The NCAC study uses decoupled simulation of the occupant's kinematics, using MADYMO software in frontal crash modes. Given the constraints of time and cost, it is a sensible approach and has been used by many researchers. In the present case, a large number of simulations were made to obtain the results for a 50th percentile male ATD and a 5th percentile female ATD in the various frontal crash scenarios. Although I have not checked the individual runs, the results shown indicate proper application.	3.5	No response required.	No change.
33	Verma	4	Occupant Kinematics Models: Since the initial position and interactions of the lower body parts determine to a significant degree the knee-to-IP loading (which dissipates most or much of the ATD's kinetic energy), it becomes important that reliable representations of ATD-to-seat and ATD-to-floor interactions be developed. In the NCAC study, the latter is simulated to various and differing (from vehicle to vehicle) levels of detail including addition of a 'foot stop' (p.33) to some models to obtain results closer to the test data.	3.5.2.2	For belted occupants some energy is absorbed by the IP through knee/lower leg interaction, but not most or much of the ATD's initial kinetic energy. Additionally, we were looking for changes from the baseline and not absolute values of risk. We made efforts to generally validate dynamic intrusions with post-test intrusions; however, measurement of dynamic intrusions is not currently available in existing test data.	3.5.2.2

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
34	Verma	4	Occupant Kinematics Models: Another challenge of MADYMO methodology is in reliably simulating the neck and the head response when impacted by airbags, specially for the 5th percentile ATD. The head deceleration and the neck forces and moments are determined by the dynamic interaction between the airbag and the occupant's head and upper torso. A decoupled MADYMO model is useful for providing trends and for obtaining 'design directions' but may not reliably predict the absolute measures of ATD's injury measures, specially for the smaller occupant.	3.7	We agree that neck forces and moments are not easy to simulate with existing software- MADYMO or FE. We were looking for changes in risks and not absolute values. Additionally, neck injury risks for belted occupants with supplemental airbags are low in the field and in our simulations. As such, the predicted neck injury risks did not substantially impact our predicted societal risks.	3.7
35	Verma	5	Occupant Kinematics Models: The restraint systems used in the NCAC study are stated as being 'generic' and not obtained from the vehicles or their manufacturers. Thus, the seatbelts and airbags likely differ significantly from those in actual production vehicles.	3.5.2.1	The models of the restraint system were obtained from restraint suppliers and are in production. They are the latest in design in terms of pre-tensioners, load limiters and airbag inflators. There were two- one for a small car and one for a mid-size vehicle. The simulation of baseline vehicles compared well with available test data.	3.5.2.1
36	Verma		Occupant Kinematics Models: Although the NCAC study states that this generic system was 'fine tuned' to match results from some high speed tests, such a forced match at one point in a domain may not denote any degree of fidelity ('real world' representation) in all the crashes. This introduces additional uncertainty in interpreting the results of this study.	3.5.2.4	Most of available crash tests are at high speeds, so we had to assume that simulations at lower speeds were predictive. We had to rely on the models for extrapolating results to lower speeds, however, our simulations are reasonable because we established reasonable correlation with available test data. As part of the occupant model development, verification and robustness checks were performed by examining trends for two occupant sizes at both 35mph and 25 mph impact speeds in NCAP, IIHS, and centerline pole impacts (Figure 3-12, Section 3.5.3, and Appendices 6-12). Simulations looked reasonable at the lower speeds from experience.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
37	Verma	5	Occupant Kinematics Models: It is stated in the report that the firing time for each vehicle's airbag was estimated from belt load time history of the NCAP tests and 'rules' were established for estimating the firing time at other impact speeds. It is not stated if in each case, the airbag was inserted into the MADYMO model at this estimated firing time and if in each case, it was simulated as fully deployed at a certain time interval prior to impact by the ATD.	3.5.2.3	The airbags in the models were not pre-inflated and the bags inflation time was dictated by the mass inflow rates of the inflators. Therefore, the bag/occupant interaction time was predicted in the model and not assumed.	3.5.2.3.
38	Verma	5	Occupant Kinematics Models: The shape and dimensions of the airbags in production vehicles are developed after many iterations and are designed to optimize protection. However, these are not used in the NCAC study. The use of generic airbag without any comparison to the physical designs in the vehicles makes it difficult to assess how these results represent physical crashes. Some degree of confidence could be established by comparing the ATD responses (trajectories, impact severities) between the MADYMO simulation and the tests at each speed.	3.5.2.1	As part of the occupant model development process, the ATD responses from the available test data were compared to the MADYMO simulation result and the majority was in good agreement. The driver airbag is similar in most vehicles- differences in vent size might exist. Tether lengths may be different. The inflators are also designed for OOP performance. As a result, driver airbag parameters are generally similar. We did not see the need for changing airbag parameters as the simulations showed good performance in NCAP and IIHS crash conditions- 4 * to 5* and "good" performance. We conducted several model runs and compared them with existing data before settling on the baseline simulations.	3.5.2.1
39	Verma	5	Occupant Kinematics Models: As a suggestion, the distinction between 'firing time' and 'instant of impact' or 'time at which fully deployed' should be clarified.	3.5.2.3	Firing time is specified at the time at which the airbag would start generating gas- the fill time of the airbag depends on the volume of the bag. This has been clarified in the report.	3.5.2.3

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40	Verma	5	Occupant Kinematics Models: Since the simulations of this in MADYMO require many simplifications and approximations, it is necessary to establish a degree of confidence in each specific event simulation by comparison with tests conducted at or near the same test speed with the same ATD and restraint system (stated on p 27, " .. before the occupant simulation matrix could be executed, it was necessary to validate each occupant model to actual crash test data to make sure the estimated injury risks are realistic and the injuries are as close as possible to real world injuries"). The NCAC study does not show numerical verifications of occupants' kinematics at 15, 20, 25 mph speeds of impact.	General	Please see answer to comment 36.	No change.
41	Verma	6	Occupant Kinematics Models: There are commercially available finite element models of ATDs and there also exist simulation capabilities to combine the vehicle and the occupants together in the same LS-DYNA model. While these combined simulations take longer to run than the decoupled MADYMO models, they have the additional capability of representing the interactions between the vehicle and the occupant (ATD) to a larger degree than decoupled models. Such combined simulations are necessary in most cases for better estimate of impact severities.	General	FE element vehicle interior were not available for most of the existing models. This is addressed in sections 3.3.4 and 3.5.	No change.
42	Verma	6	Crash Configurations and Mapping to Real World Risk of Injury: The frontal crash parameters selected for this study from analysis of NASS CDS database appear to represent a sufficiently wide range of frontal crashes (except crash speeds, as discussed below). Similarly, the selection of 'full engagement' and '50% offset' crash modes for vehicle-to-vehicle crashes represent the configurations likely to 'bound' the existing data and are therefore an acceptable range (of this parameter) for initial estimates of trends.	3.6	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
43	Verma	6	Crash Configurations and Mapping to Real World Risk of Injury: The major question in regards to the results from NCAC study is in the selected crash speeds for single vehicle crashes as well as for vehicle-to-vehicle crashes. The NCAC study selections are biased towards higher speeds of crashes which are fewer in number as shown by the NASS CDS data. In order to properly represent the current fleet-wide observations (p. 54-55), it is necessary to include barrier equivalent speeds of 0-11 mph which predominate in the field events. This (inclusion of 0-11 mph crashes) may change the study's numerical outcome because the relatively large numbers of these mph crashes may significantly affect the weighted sums. It should be noted that for some vehicles, this speed range may be a boundary between airbag deployment and non-deployment decisions. This has implications for simulation of the ATD response.	3.8	It is true that crash involvement in this speed range is high, but somewhat underrepresented in NASS due to the tow-away criterion for inclusion. This speed range also covers the grey-zone for airbag deployment that differs between vehicles. Simulating these crashes with the occupant model would require simulations of airbag deployments and non-deployment conditions. To be able to predict injuries, we will require accurate stiffness characteristics of the steering wheel that are generally not available. Our selection of the lowest speed range 12+ mph was predicated on airbag firing, and also on the analysis of NASS data that showed a small number of MAIS3+ injuries (around 10%) in the 0 to 11 mph speed range. In this speed range (0-11 mph), the bumper characteristics predominate the response of the vehicle requiring low-speed damageability data for model validation. Such data are generally not available.	Clarify in section 3.8

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
44	Verma	6	Crash Configurations and Mapping to Real World Risk of Injury: The NCAC study states that the front crash parameters in the NCAC are obtained by analyzing NASS CDS data for identifying such parameters and all the frontal crash modes are then represented by three types of crashes. Although not stated, the reason for selecting these types appears to be that many crash tests have been conducted of these types and are available in the literature. The three types utilized in the study are- full frontal impact with a rigid barrier, an offset crash with deformable barrier and a vehicle-to-rigid pole impact. This selection has the advantage of utilizing existing knowledge (and existing levels of familiarity and confidence) of these models and is therefore a suitable step for developing the methodology and for 'preliminary' estimate of feasibility. However, as stated earlier, the crashes observed in the field are mostly at lower speeds and are different from NCAP and the IIHS ODB tests in many respects. Therefore, it is recommended above to modify crash configurations and simulated speeds to better represent the observed data.	3.6	No response required.	No change.
45	Verma	7	Crash Configurations and Mapping to Real World Risk of Injury: Some information also needs to be provided to explain the selection of vehicle-to-pole impact as a surrogate for 'front impacts between rails'.	3.8.1	The localized deformation of the vehicle-to-pole test is representative of between rail structural engagements in frontal crashes.	3.8.1
46	Verma	7	Crash Configurations and Mapping to Real World Risk of Injury: The high speed impact simulations, where the study's verification and validation efforts have been concentrated, represent 'extreme' crash configurations that are a very small fraction of field events. More work needs to be done to improve the LS-DYNA and the MADYMO modeling methodologies to make them representative at the more common, lower speed crashes.	3.6	Better estimation of low speed kinematics and ATD responses are outstanding long terms research needs as current ATDs and injury criteria were not developed for the lower crash conditions. This is outside of the scope of this study.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
47	Verma	7	Crash Configurations and Mapping to Real World Risk of Injury: The next step in creating macro-level models of fleet-wide automotive safety is to introduce probability estimates in the FEM formulations. This concept has been discussed in the past and the existing computation capabilities are capable of handling such simulations.	General	Stochastic or probabilistic studies were outside the scope of this study.	No change.
48	Verma		Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: In the report, the calculation of combined injury risks for the entire fleet is based on a weighted sum of injury risk from individual crashes. This assumes the injury risks to be a linear function and ignores the second-order terms. Generally, this provides a 'lower bound' of the overall sum and this approach is widely used in estimating domain-wide results and creating 'first estimates'.	3.8	The overall injury risk is simply based on frequency of occurrence (weight) of each crash incident. The overall risk is simply additive and there is no assumption of linearity.	No change.
49	Verma		Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: In addition, the study assumes that the population is adequately represented by the 50th percentile male ATD and the 5th percentile female ATD. This is a major assumptions and the reason for it appears to be that these are the only two sizes of ATDs currently available and in wide use for front impact testing. This assumption needs further testing.	General	There are only 50^{th} and 5^{th} percentiles ATDs and corresponding crash tests to work with. It would be nice to simulate a continuum of occupant sizes, but it was not practical within the timing and scope of the project. Additionally, models of different size occupants would have to be developed and they would be open to the same questions of test validity, etc. It should be noted that for nearly thirty five years, safety standards and policies were set around the 50th percentile male dummy only	No change.
50	Verma		Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The NCAC study does not include considerations of the effects of age on the risk of injuries. This aspect should be investigated further since the projected US population for the 2025 timeframe is likely to be older and the distribution different from today's population pyramid.	General	We agree that it is important to study the effects on the aging population and could be considered for future studies, as highlighted in section 6.2.	6.2

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
51	Verma	7-8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The methodology in this study is an important step forward in demonstrating feasibility of the approach but the numerical results of this study cannot yet be considered to be 'real world' estimates of the effects of automobile mass reduction on front impact safety. There are multiple reasons for this opinion: - the crashes simulated in the study do not represent the full spectrum of frontal crashes, - little or no verification is provided for vehicle & occupant models at 15,20, 25 mph which constitute most of the frontal crashes, -the models of the driver' kinematics are not based on actual seatbelts and airbags used in the vehicles, -the many simplifying assumptions in seat and floor models are not verified for adequacy and applicability, - two of the partner vehicle designs contribute heavily to the overall numerical results but are not shown to be viable or feasible vehicles for the 2017-2025 fleet, - the report's authors point to several difficulties and issues/inconsistencies in the findings (p.84, p.82, p.86, p.89,p.90) and these need to be addressed before the study's results can be used in product- or policy-related decisions. Many of the above points relate to the current state of knowledge in finite element simulations of vehicle-to-object and of occupant-to-vehicle interior impacts. These could be addressed by additional research work supported by a limited number of tests at points of high sensitivity.	General	No response required. Addressed in responses to previous comments.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
52	Verma	8	Other Comments: The methodology used in NCAC study is innovative and as such, the study is of significant value in illustrating the viability of the concept. It is also valuable because it clearly identifies the shortcomings and the need for additional research. However, the numerical findings of this study do not yet provide a reliable forecast of the effects of automotive mass reduction for the 2017-2025 fleet.	General	No response required.	No change.
53	Verma	8	Other Comments: The current NCAC study should be considered one significant step in developing methodologies to evaluate relationship between overall (fleet-wide) safety) and mass reduction of automobiles. More steps are necessary and the underlying technologies (simulations) need to be improved before the answers are of value. Most importantly, other crash modes and occupant sizes/age may need to be added to the model to make it fleet-representative. It is also essential that all other crash modes (lateral, rollover, etc.) be included along with the frontal impacts in making any projections. As is well known, changes in vehicle design can have different effects in different crash modes.	General	No response required.	No change.
54	Verma	8	Other Comments: It is a concern that the numerical results of the present study, although based only on frontal impact simulations of limited capability may be misinterpreted by some as supporting the opinion that 'less mass means less safety'. Such opinion will be premature and may not be technically justified.	General	In the report overall, and in the Summary and Conclusions specifically, it is clearly stated that EFP was developed and demonstrated for frontal crash modes.	Overall, sections 5 and 6

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
55	Gabler	2	Vehicle Structural Models: I concur with the report's conclusions that the Venza FE model does not appear to be correct. As shown in Figure 4-25, the 20 and 25 mph frontal offset crash pulses from the FE model are suspect. In addition, the study reports that many of the Venza FE models terminated abnormally. As recommended by the report, the model should be validated before reporting any findings using the Venza model.	4.2.3.1	No response required.	No change.
56	Gabler	2	Vehicle Structural Models: The choice of the 2001 Ford Taurus, 2003 Ford Explorer, 2007 Chevy Silverado, and 2010 Toyota Yaris are reasonable surrogates to represent the collision partners which broadly cover the range of expected passenger vehicle collision partners which the lightweighted vehicles could expect to encounter.	3.3.2	No response required.	No change.
57	Gabler	2	Vehicle Structural Models: The only caveat is that two of the FE models (the 2001 Taurus and 2003 Explorer) are FE models of 10+ year old designs. The automakers have made numerous structural modifications to their vehicle designs in the last 10 years in response to tests such as the IIHS frontal-offset crash tests and to improve crash compatibility under the voluntary "Enhancing Vehicle-to-Vehicle Crash Compatibility Agreement (EVC)" established in 2003. I raise this issue as the goal of the Systems Model is to project the performance of lightweighted vehicles in future fleets, perhaps for the 2018 timeframe, when few of these 2001-era vehicles will still be on the highways.	3.3.2	Both the Taurus and the Explorer were rated "Good" in the IIHS 40% Offset tests at 40 mph. The 2003 Explorer rails were lowered compared to the previous model to provide geometrical compatibility with cars and would have met the guidelines agreed to by the Industry. We do not see the current and future designs to be radically different from the two vehicles in question. The Explorer was a body-on-frame design and the trend is towards unitized body for SUV's. However, Pickups are expected to continue as body-on-frame vehicles, and some will be in the same weight class as the Explorer. Future studies will include more modern vehicle designs like the Accord or the Camry replacing the 2000 Taurus from the fleet, and potentially adding a unitized body SUV, e.g. Venza, into the fleet model. The results of a follow-up study will shed some light on the robustness of the results of this initial study.	3.3.2.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
58	Gabler	2	Vehicle Structural Models: The FE models of the older Taurus and Explorer may still be suitable for the Systems Model, but the report would be improved by examining and discussing this issue. One way to do this would be compare crash test results, e.g. estimates of vehicle stiffness, crash pulse, intrusion, of these older vehicles with their newer 2013 and later counterparts.	3.3.2	See response to previous comment.	No change.
59	Gabler	2	Vehicle Structural Models: The report (Table 3.7, p.20) indicates that the 2010 Toyota Yaris model is still under development and that the model has not yet been validated against NCAP crash test. It is unclear if this was the status of the model when the study was performed. If an unvalidated model was used, is the intent to rerun the results after validation of the Yaris model?	3.3.2	The Yaris model development was completed before the simulations were run. The table has been updated.	3.3.2
60	Gabler	3	Occupant Kinematic Models: One crucial assumption and limitation, acknowledged in the report, is that the study uses the same restraint system for both the baseline vehicles and the lightweight variants of these vehicles. The automakers highly optimize restraint systems for each vehicle design, and it would be unlikely that the lightweight variants of the target vehicles would have the same restraint systems as their baselines. The restraint systems optimized for the lightweight variants could be expected to have a lower injury risk than if the baseline restraint system was installed without alteration in the lightweight variant. Hence, the use of generic restraint systems would likely contribute to overestimation of the injury risk for the lightweight variants.	4.4.5	See to responses to comment 12 and 13 above. The restraint systems for the baseline, comparator vehicles were also not optimized. In as much as the variants met or far exceeded the frontal regulations currently in effect, and yielded results that would have garnered good ratings from the IIHS and NHTSA's NCAP, no need to optimize the restraint system was attempted in this study. Current regulation and consumer information testing does not require a manufacturer to design a vehicle for optimum performance across all speeds and against all partner vehicles and objects. A major finding of this study, though not emphasized enough in the report, is that the vast majority of serious-to-fatal injuries occur at speeds that are substantially below the crash speeds in regulations, NCAP or other public domain tests. Exercises with the current model can lead to the development of strategies for further reduction of societal risks across all speeds and objects contacted.	4.4.5

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61	Gabler	3	Occupant Kinematic Models: The Toyota Venza, one of the target vehicles, is equipped with a knee airbag. However, the knee airbag was not included in the occupant simulation models of the Venza. I would expect that the presence/absence of the kneebag would substantially affect occupant responses.	A-8	The Venza does have a knee airbag which was not included in the occupant simulation models in this initial study. We agree that the presence/absence of the knee bag could substantially affect occupant responses and will be considered in future studies. However, the femur loads were similar and low in our Venza simulations and, therefore, the femur injury risks were equivalent as the changes from the baseline were of interest.	3.5.2.1
62	Gabler	3	Occupant Kinematic Models: Section 4.4 provides a nice discussion of the limitations of the occupant models. This section can be used as a roadmap for further development of the occupant models. Limitations include lack of a model steering column linkage system which is required to accurately model steering wheel intrusions. There is also a need in general for improved modeling of occupant compartment intrusions. This first iteration of the Systems Model has decoupled vehicle structural modeling (performed in LSDYNA) from occupant modeling (performed in MADYMO). Intrusions from LSDYNA are used as prescribed inputs to MADYMO. While this is a reasonable approach for this first iteration of the Systems Model, there is a need for much more accurate modeling of occupant compartment intrusion. I concur with the report's recommendation that intrusion and occupant modeling be conducted in LSDYNA or a similar FE code in future iterations of the Systems Model.	4.4	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
63	Gabler	3	Occupant Kinematic Models: The report presents a nice analysis which checks the "5-30" algorithm against the actual airbag firing times observed in crash tests. However, this validation was limited to available crash tests (a 47kph frontal-offset Transport Canada crash test for the Taurus and a 56kph full frontal NCAP crash test for the Yaris). It is unknown however how well these results will generalize to other crash modes, e.g. frontal-pole crashes, differing degrees of frontal-offset, or lower impact speeds. Airbag firing times and deployment strategies are likely to vary with crash mode and with occupant position.	3.5.2.3	As mentioned by one of the reviewers, airbag firing algorithms are not publicly available. However, the firing times in available crash tests of each vehicle at various velocities were carefully studied and established- the best that could be done. A follow-up study can be conducted with sensor suppliers in the future. In the case of an Accord variant, the sensitivity of occupant responses to firing time was noticed. The selected firing time was the most reasonable for the vehicle considering available test data. It should be noted that the current state-of-the-art in FE or any other modeling for airbag sensor responses is not predictive. The common practice in crash sensing for airbag firing relies heavily on tests supplemented by modeling.	3.5.2.3
64	Gabler	4	Occupant Kinematic Models: The report on validation of the Venza airbag firing timing is incomplete. The report does not identify which crash test was used to obtain the Venza airbag firing time, and unlike the Taurus and the Yaris, the report also does not present the shoulder belt loads vs. time or vehicle displacement history for the Venza. It would be useful to identify the crash test and include these plots so that the Venza airbag firing time can be checked.	3.5.2.3.3	The Venza baseline occupant model with the Hybrid III 50th percentile male dummy was evaluated against available full frontal crash data, the NHTSA test 6601, as noted in Appendix 8. The "5-30" rule was used to estimate the firing time from the FE crash pulse and the firing time came to 18 ms. The Venza occupant model is currently being improved for a follow on study and will be reported on with more extensive documentation of the model validation.	Appendix 15.
65	Gabler	4	Occupant Kinematic Models: Follow-on studies should check the "5-30" algorithm against actual firing times recorded in frontal-offset and pole crash tests. A second approach which should be considered would be to obtain airbag firing times that are recorded in real-world EDR data. The EDR data could provide the firing time for both the first and second deployment stages as a function of crash mode, delta-V, and occupant position.	3.5.2.3	The suggested checks and approach of investigating real world recorded EDR data to obtain airbag firing times was included in the section on Potential Refinements of EFP.	6.1.3

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
66	Gabler	4	Occupant Kinematic Models: The methods used by this study to assess occupant injury risk follow accepted practice used in the crashworthiness research community.	General	No response required.	No change.
67	Gabler	4	Crash Configurations and Mapping to Real World Risk of Injury: The study used BES as a surrogate for impact speed, however in a very clever way. FE simulations were run using BES, but primarily as a simulation initial condition to get a crash pulse. The crash pulse was then used to drive the occupant models. The essential effect of this approach was to ensure that the resulting crash pulses were applied with a reasonable statistical weight.	General	No response required.	No change.
68	Gabler	5	Crash Configurations and Mapping to Real World Risk of Injury: Now that the FE modeling is complete, the study should check out the validity of their assumption that BES can be used as surrogate for impact speed. The distribution of the delta-V values computed in the FE models should be easy to check against the corresponding distribution of delta-V obtained from NASS/CDS for these vehicle models. If BES as impact speed was a good assumption, the two delta-V distributions should be fairly comparable.	3.2.2	Such further studies are useful but are beyond the scope of current studies.	No change.
69	Gabler	5	Crash Configurations and Mapping to Real World Risk of Injury: Future studies should consider other methods of obtaining vehicle impact speed distributions. One promising approach would be to use the vehicle pre-crash speed which is recorded in EDRs in real-world crashes. A second approach would be to seek out and analyze in-depth crash databases which, through enhanced reconstruction methods, have determined impact speed for large numbers of cases. In the U.S., one such candidate database is the NCHRP 17-22 database of single vehicle crashes. A second possibility would be to use European or other international in-depth databases which have reconstructed impact speed.	3.2.2	Agree with further studies that were beyond the scope of this one.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
70	Gabler	5	Crash Configurations and Mapping to Real World Risk of Injury: The report should present the distribution of driver age in the U.S. population of belted drivers. It is important to carefully evaluate the study decision to limit the analysis to drivers of age 16 to 50 years of age. My concern is that older drivers are at substantially higher risk of injury in crashes than drivers in this younger age range. Older drivers also account for a substantial fraction of drivers regardless of injury level. An analysis of NASS/CDS 1997-2011, which I conducted for this review, indicated that belted drivers 51+ years old account for 23% of drivers, but over 34% of MAIS3+F drivers. Limiting driver age to 16-50 year olds was used as a simplifying assumption in this first iteration of the study. However, this assumption may have a potentially huge influence on the study findings. The report should discuss how omitting older drivers affects the likely findings.	3.2.2	Given the proven increase in injury tolerances for the older occupants, including the older driver could affect the findings. Future studies could address this group separately and incorporate in the societal risk computation. It is important to note different risk functions would be needed for the older driver and possibly different crash involvements rates.	5 (intro) and 6.2
71	Gabler	5	Crash Configurations and Mapping to Real World Risk of Injury: Figure 3-7 indicates that cars and pickup trucks have the same risk of injury up to 60 kph. The outlier in this graph appears to SUVs. The figure indicates that SUV risk is lower than both cars and pickup trucks across the range from 0 to 60 kph. This is counter-intuitive. I would expect that pickups are more like SUVs than like cars. It would be useful for the report to discuss this finding.	3.2.2	The discussion is included in section 3.2.2 and noted that the SUVs include the CUVs for this study.	3.2.2
72	Gabler	5	Crash Configurations and Mapping to Real World Risk of Injury: This study does not consider the performance of the target lightweight vehicles in front-side or front-rear crashes. Lightweighted vehicles are likely to be fitted with stiffer frontal structures which could make these vehicles more aggressive or incompatible with their side struck collision partners.	General	By constraints of time and model availabilities, this study concentrated on only frontal impacts and was a “proof-of-concept.”	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
73	Gabler	6	Crash Configurations and Mapping to Real World Risk of Injury: The challenge which this project faces is to predict the societal risk incurred by lightweight vehicles and their collision partners in a future fleet. The report does not speculate when these lightweight vehicles might compose a significant fraction of the fleet, but a reasonable estimate would be five years from now or 2018. The report is correct in stating that one limitation of this study is that EFP must use models of MY2001-era vehicles to represent the mix of collision partners in the year 2018. Because of the enormous expense of building new FE models, there is little else that the study could do other than use existing models of MY2001-era cars. However, the report should consider stressing this limitation to readers who are assessing the societal injury risk associated with light-weighting vehicles.	1.2	This concern has been added to the conclusion section.	6
74	Gabler	6	Crash Configurations and Mapping to Real World Risk of Injury: Likewise, the set of statistical distributions computed from 1985-2010 NASS/CDS may also be substantially different than will be observed in NASS/CDS 2018. New technologies, e.g. automatic emergency braking, for example could produce radically different impact speed distributions in future fleets. Likewise, as Lane Departure Warning and automated lane-keeping systems are more widely deployed, we can expect a much lower incidence of single vehicle, road departure crashes into fixed objects, e.g. poles. Prediction of these future collision distributions was not the goal of EFP, but should be pointed out to readers and policymakers who are evaluating the effect of light-weighting vehicles.	General	True, but need effectiveness estimates of future technologies to predict the crash environment in the future. This was outside the scope of this study and would be a major task. Once a change in crash topologies is established, e.g. changes due to effectiveness of crash avoidance technologies, EFP could be applied to estimate societal effects.	6.2

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
75	Gabler	6	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The combination of systems modeling with detailed FE models of proposed future lightweight vehicle designs is a major plus of this project and engineering approach. It allows fleetwide evaluation of crashworthiness long before construction of physical prototypes. Systems Modeling permits crashworthiness evaluation across the full range of crash conditions that a vehicle is likely to experience if it were implemented on U.S. highways, and evaluation of occupant protection across the full spectrum of drivers likely to operate the vehicle.	General	No response required.	No change.
76	Gabler	6	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: A crucial component of the EFP is its consideration of not only protection of its own occupants (self-protection), but also the study's consideration of the injury risk to its collision partners (partner-protection). Traditional crash tests, e.g. NHTSA full frontal NCAP crash test, only consider the protection of the subject vehicle occupants. However, the unintended consequence of this approach is that vehicle designs which protect the subject vehicle's occupants may do so at the expense of their collision partners. EFP is a far superior method as it considers the injury risk to all persons involved in a crash with the target vehicle.	General	No response required.	No change.

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77	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: With all due respect, my biggest criticism of the report is that it is overly modeling-centric. The over-arching goal of this study is to determine the effect of new designs upon 'Societal Injury Risk' (SIR), and it was less than ideal that the reader must wait until page 49 in the report to see an explanation of what is meant by this key concept. Because the primary objective of this study is to determine fleetwide safety benefits, a description of the metric by which fleet benefits will be judged should be introduced early in the report. I recommend moving this entire section (section 3.7.4) to the beginning of Chapter 3 rather than leaving it to the end.	3.7.4	A new section is now included at the beginning of Chapter 3 which defines societal injury risk in EFP. The governing equation to compute societal injury risk and the hypotheses upon which the formulation of the governing equation is based are also provided.	3.1.1
78	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The study would greatly benefit by a more thorough definition of what is meant by 'Societal Injury Risk'. The equations in section 3.7.4.1 should be clarified to more precisely define SIR. My assumption is that SIR is a probability, but it was unclear either from the text or the equations what target population the probability pertained to. Is the target population all occupants, all drivers, all drivers in frontal crashes or all drivers in tow away crashes? Because the crash statistics presented were from NASS, my interpretation in reading section 3.7.4.1 was that SIR was the probability of MAIS3+ injury in all drivers in frontal crashes. However, I became less certain after reading section 3.8.3 in which the study reported using GES (police reported as opposed to tow away crashes) for some of the weights.	3.7.4.1	See answer to comment 77 above.	3.1.1

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
79	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: It would be helpful to remind the reader in the lead paragraph of section 3.7.4 of how the study categorizes injury versus non-injury. A precise definition of injury is critical in order to understand later statements on injury. For example, the paper states that 0-11 mph crashes were not simulated because no injury was expected. However, these low speed crashes could certainly produce MAIS1 injuries, but in this study, my read is that MAIS1 or MAIS2 occupants would be considered uninjured. The approach of this study was to base SIR on the risk of serious injury (MAIS3+) rather than a risk of any injury. Is this correct?	3.7.4	The approach of this study was to base SIR on the base the risk of sustaining a serious (MAIS 3+) injury or a fatality, referred to as the MAIS 3+F risk. The reader is now reminded in the lead paragraph of section 3.7.4 We have accounted for MAIS3+ injuries for various reasons. Primarily, it is because injury risk functions relating the probability of injury to a body region with dynamic responses of the body region predicted by tests or simulations are available through past biomechanical research. The definition of the AIS 1 (i.e. minor) injuries varies a lot- a minor cut or bruise to “whiplash” type of injuries. We have similar issues with AIS2 injuries- injury risk functions not available, although they could be developed for the body regions of interest, but also open it up for further criticism.	3.7.4
80	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: Please define what is meant by ‘Exposure Rate’. Is this in units of drivers, drivers/year, or a frequency? It appears from section 3.8.1 that exposure rate is a frequency. If so, the term ‘Exposure Rate’ should be reworded as a frequency is not a rate. My read of these equations is that exposure rate appears to be a conditional probability. Rather than “Exposure Rate for Full Frontal, SUV” a better, more conventional wording would be “Probability of Full Frontal Crash involving a SUV”	3.8.1	“Exposure Rate” has been defined as “crash involvement frequency”.	3.7.4.1
81	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: Please define what is meant by ‘Weighting Factor’. Are the units in terms of drivers, drivers/year, or a frequency? Are the weighting factors absolute numbers (as used in some studies) or probabilities (as used in other studies)?	3.2.2 3.8	“Weighting Factor” has been defined as “percent of occurrence” throughout the report.	

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82	Gabler	7	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: Section 3.7.4.1 should cite the source (Laituri) for the 0.75/0.25 split between mid-sized males and small statured females. This is explained later in the report, but the 0.75/0.25 constants were used in the equations in 3.7.4.1 without explanation and made the equation difficult to interpret. Alternatively, the report could simply replace the 0.75/0.25 constants with variables and then give the specific values from Laituri later in the report.	3.7.4.1	Laituri at all 2003 were cited for the 0.75/0.25 split between mid-sized males and small statured females in section 3.7.4.1.	3.7.4.1
83	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: In Table 3-32 and Table 3-33 (page 57), the report uses NASS/GES to define the distribution of two vehicle crash types, e.g. car-to-car, or light truck to light truck. Please provide the rationale for the use of GES. All other parts of study have relied almost exclusively on NASS/CDS to estimate related distributions. GES and CDS samples use very different inclusion criterion (CDS is a sample of all tow away crashes while GES is a sample of all police-reported crashes). The report should discuss what bias switching from CDS to GES with their differing sampling strategies may introduce into the results.	3.8.3	This has further clarified in report. Distributions of crash exposure by vehicle class are based on NHTSA's 2012 TSF (Traffic Safety Facts). There is no bias since GES only give us the exposure, i.e. how often a crash occurs.	3.8.3
84	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The caption for Table 3-32 states that the data in this table was developed using crash distributions and registration data from 'Traffic Safety Facts'. It would be useful to provide additional detail on how registration data was used to compute this table.	3.8.3	The source is TSF (which uses registration data). The reference to registration data was removed.	3.8.3

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85	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: Table 3-32 and Table 3-33 present crash pairings from the GES analysis which appears to contain all crash modes (frontal, side, rear, etc.). The EFP study however focuses entirely on frontal crashes. My concern is these GES distributions may not be applicable to the target of frontal crashes which the study is examining. The study should consider either restricting Table 3-32 and Table 3-33 to frontal crashes only, or alternatively showing that there is no statistical difference between the crash pairing for all crashes and frontal-only crashes.	3.8.3	In this study, we are assuming that there is no bias in the crash pairing distributions in frontal crashes as compared to all crash modes. This assumption can be reevaluated in future development of the EFP.	3.8.3
86	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The paper states "For the car class, a 50/50 distribution of PCs <3000 lbs. and PCs >3000 lbs. and a 50/50 distribution for SUVs and Pickups in the Light Truck (LT) Class are assumed, shown in Table 3-33." What is the basis for making this assumption? This exact distribution can be readily computed from either NASS/CDS or NASS/GES. The paper would benefit from using the actual distribution in the study of fleet benefits rather than using this assumed distribution.	3.8.3	For the car class, a 50/50 distribution of PCs <3000 lbs. and PCs >3000 lbs. and a 50/50 distribution for SUVs and Pickups in the Light Truck (LT) Class in the US Fleet are assumed in this study. This distribution would be available from vehicle registration rather than crash exposure. This assumption can be reevaluated in future development of the EFP.	3.8.3
87	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: One limitation of the study is that the analysis is limited to consideration of drivers of age 16 to 50 years of age. Older drivers are at substantially higher risk of injury in crashes than drivers in this younger age range. The reports points out this limitation and states "It has been shown that adult occupant injury tolerance decreases with age and the elderly group has a higher risk of injury than the younger age group at any given crash delta-V…. This requires different risk functions for elderly group which is not included in this phase of the project."	3.2.2	As noted in 3.2.2, the rationale was to have consistent age groups with available injury risk functions, as we were comparing the variants to baseline. The Societal Injury Risk (SIR) was further qualified to for population under study.	Executive Summary and 3.7.4.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
88	Gabler	8	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The study made this simplifying assumption in this first iteration of EFP. However, inclusion of the older driver group (> 50 years old) needs to be a priority improvement to the model. Designs which optimize younger driver safety (by for example stiffening the structure) may result in a substantial disbenefit for older, more frail drivers. The concern is that any benefit for younger drivers may be overwhelmed by the disbenefit for older drivers.	3.2.2	See answer to comment 70 above. We agree that it is important to study the effects of structural changes on the aging population.	5 (intro) and 6.2
89	Gabler	9	Combining Individual Occupant Injury Risk into Overall Injury Risk for the Fleet: The study would benefit by validating the fleetwide model predictions for the baseline vehicles against the actual real world injury counts tabulated in NASS/CDS. Specifically, the study should compare the actual risk as measured by NASS/CDS for each of the 3 baseline vehicles (Taurus BL, Accord BL, and Venza BL) against the societal risk predicted by EFP for these baseline vehicles. NASS/CDS contains the number of MAIS3+ drivers for each baseline vehicle in exactly the same configurations for which EFP simulations were conducted.	General	This is not the goal of this this study. NASS/CDS does not have sufficient data to evaluate particular car lines.	No change.
90	Gabler	9	Other Comments: As noted earlier in this letter report, Systems Modeling is a superior method to traditional techniques, e.g. crash testing, for evaluating the crashworthiness of existing or proposed vehicle designs. The Systems Modeling methodology, presented in this report, evaluates vehicle crashworthiness across the full spectrum of crash modes, collision partners and potential drivers which a vehicle is likely to experience on U.S. highways. The result is a much more robust of societal injury risk than can ever hope to be provided by a small number of crash tests.	General	No response required.	No change.

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
91	Gabler	9	Other Comments: I interpreted this study as a pilot or feasibility study of Systems Modeling. Although the analysis described in the subject report is very comprehensive, it is important to point out that the study considers only a subset of potential frontal crashes and is applied to a select subset of drivers. Not considered are drivers over age 50, an age group particularly vulnerable to crash injury. Likewise, the study does not model frontal-side crashes in which the lightweighted vehicle strikes a collision partner in the side. Not considered in this pilot study are the tradeoffs between making a lightweight vehicle stiffer for better frontal occupant protection and the potential side effect that stiffer, lightweight vehicles are likely to be more aggressive or incompatible with their side struck collision partners.	General	This comment is a summary of previously stated concerns. Occupant age is addressed in comment 70 and 87. Application to other impact configurations and design tradeoffs are addressed in comment 72.	No change.
92	Gabler	9	Also, not considered by the model is the injury risk for unbelted occupants. In the U.S., only about 15% of occupants are unbelted, but this small fraction accounts for approximately 50% of all fatalities.	General	Unbelted occupants fell outside the scope of this study. However, if unbelted occupant models are developed and validated, these can easily be used and integrated into the methodology.	No change.
93	Gabler	9	Other Comments: I want to emphasize again that the authors have done a superb job in assembling the Systems Model. But the results of this pilot study should be used with caution in drawing any immediate policy conclusions as the issue of older drivers and side crash compatibility remains to be evaluated. Follow-on improvements to EFP, many of which were outlined in the subject report, should be actively pursued to obtain an improved fleetwide assessment of societal injury risk.	6.1	No response required.	No change.
94	Gabler	10	Other Comments: Spell out all acronyms, e.g. CARB, EPA, BL, LW, etc. These acronyms are defined in the report, but the executive summary should be stand-alone.	1	Acronyms have been spelled out in the executive summary.	1
95	Gabler	10	Other Comments: The equation in Figure 1 shows that risk is computed as summing over all occupant locations in each car. However, this study only considers drivers. The summation over all occupants is unneeded.	1.2	Summation over all occupants was removed and drivers indicated in the text.	1.2

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
96	Gabler	10	Other Comments: The indices in the weights in the equation in Figure 1 and the following paragraph are inconsistent. The weights in Figure 1 are specified as Wjklmnop while the weights in paragraph following this paragraph are listed as Wijklmn and later in this paragraph as Wijklmnop.	1.2	The indices have been corrected.	1.2
97	Gabler	10	Other Comments: On p.3 of this chapter, the report states that it was Volpe in 2000 which first used AIS to score injury severity. The report should be corrected to show that the University of Virginia included AIS in their revisions to the SSOM model in the early 1980s. The report should consider citing the following as a reference for this: White KP, Pilkey WD, Gabler HC, and Hollowell WT, “Simulation optimization of the crashworthiness of a passenger vehicle in frontal collisions using response surface methodology," SAE Paper 850512, SAE Transactions, Journal of Passenger Cars, Section 6, (1985)	2.1.3	Included in section 2.1.3	2.1.3
98	Gabler	10	Other Comments: Figure 3-1 shows that Fleet FE and Target FE models were used as input to the EFP model. But FE models were only used for the vehicle structure. Madymo models were used for the occupant interior. Consider changing the labels in this figure to show “Fleet FE and Madymo Models” and “Target FE and Madymo Models”	3.1	Figure 3-1 has been updated to indicate “Fleet Models” and “Target Models”. The figure is intended as an overview of the EFP approach and not just the initial implementation in the current study.	3.1
99	Gabler	10	Other Comments: Table 3-4 shows weighted values of frontal crash involvement and serious injury. It is not possible from this table however to judge what sample size these values are based. It would be beneficial to provide a table like Table 3-4 with unweighted values.	3.2.3.2	The unweighted NASS data has been included in Table 3-4.	3.2.3.2
100	Gabler	10	Other Comments: Table 3-12, Table 3-13, Table 3-14 and Table 3-15 should provide units of measure.	3.5.2.3.1 3.5.2.3.3	Units have been included in caption.	3.5.2.3.1 3.5.2.3.3

Comment Number	Reviewer	Page in Peer Review Report	Comment / Suggestion	Commented Section	LW Team Response	Location of Response
101	Gabler	10	Other Comments: Figure 3-9 provides an equation for 'Accumulated Injury Risk' without defining what this is. I assume that this is the same as 'Societal Injury Risk' (SIR) or total risk presented elsewhere in the report.	3.2.4	The equation in Figures 3-9 has now been defined in section 3.1.1.	3.2.4
102	Gabler	10	Other Comments: The equation in Figure 3-9 for total risk is not consistent with the equation for total risk presented in Figure 1 or the equation for SIR presented in Section 3.74.	3.2.4	The equation in Figure 3-9 for total risk has been corrected.	3.2.4
103	Gabler	11	Other Comments: On Table 3-32, the note "HT are heavy (10,00lbs)" appears to have a missing zero.	3.8.3	The correction had been made in the report.	3.8.3
104	Gabler	11	Other Comments: In Table 3-33, the table heading has a misspelling. 'paring' should be 'pairing'.	3.8.3	Correction made.	3.8.3
105	Gabler	11	Other Comments: In the caption for Table 3-22, the term SRI should be replaced with SIR.	3.7.4.1	The caption has been clarified to refer to "Societal Risk I" which is defined in section 3.7.4.	3.7.4.1
106	Gabler	11	Other Comments: In Section 3.7.4.1, should 'Societal Risk' be labeled as 'Societal Injury Risk'?	3.7.4.1	'Societal Risk' has been replaced by the intended 'Societal Injury Risk' throughout the report	All sections

Appendix A:

Curriculum Vitae and Resumes

Kurt Fischer's Curriculum Vitae

Education: Bachelor of Science Degree from the University of Michigan, 1984

Experience:

- 1984-1985 LTV Aerospace and Defense – Product Engineer responsible for enhancing and maintaining military trucks.
  Projects included roll bars for ¼ ton Jeeps, fuel system re-design, and resolving clutch failures.
- 1985-1987 General Motors – Manufacturing Engineer responsible for developing automated engine assembly processes
  Projects included a piston insertion process, secondary force balancer assembly and quality control metrics.
- 1987-Present TRW Automotive – Senior Staff Engineer and Technical Specialist responsible for frontal core system development.
  Projects include developing next generation restraint systems
    1. Adaptive restraints
    2. Air bag out-of-position injury mitigation
    3. Rear seat occupant protection

Recognitions:

Licensed Professional Engineer since 1989 in the State of Michigan

TRW Chairman's Award in 1998

Received of 40 patents

Dr. Clay Gabler's Curriculum Vitae

Department of Biomedical Engineering
School of Biomedical Engineering and Sciences
Virginia Tech
gabler@vt.edu

EDUCATION
Ph.D. Mechanical and Aerospace Engineering, Princeton University, 1998
M.A. Mechanical and Aerospace Engineering, Princeton University, 1994
M.E. Nuclear Engineering, University of Virginia, 1980
B.S. Nuclear Engineering, University of Virginia, 1976

ACADEMIC EXPERIENCE
2011-present Professor, Biomedical Engineering,
Professor, Mechanical Engineering
Virginia Tech
2005-2011 Associate Professor, Biomedical Engineering,
Associate Professor, Mechanical Engineering
Virginia Tech
2006-present Associate Department Head School of Biomedical Engineering and Sciences
Virginia Tech
1998-2004 Associate Professor, Mechanical Engineering, Rowan University

INDUSTRIAL EXPERIENCE
1984-1998 Research Program Manager, National Highway Traffic Safety Administration, U.S. Department of Transportation
1983-1984 Research Engineer, University of Virginia
1976-1983 Research Engineer, Babcock & Wilcox Co.

PROFESSIONAL AFFLIATIONS
Society of Automotive Engineers (SAE)
American Society of Mechanical Engineers (ASME)
Association for the Advancement of Automotive Medicine (AAAM)
Biomedical Engineering Society (BMES)
Institute of Electrical and Electronics Engineers (IEEE)
American Society for Engineering Education (ASEE)

HONORS AND AWARDS

- Fellow, Association for the Advancement of Automotive Medicine (AAAM, 2012)
- Fellow, Society of Automotive Engineers (SAE, 2009)
- Outstanding Mechanical Engineering Doctoral Student (Faculty Advisor, 2013)
- Biomedical Instrumentation Sciences Symposium Chair's Award for Student Competition (Faculty Advisor, 2012)
- Virginia Tech College of Engineering Outstanding Service Award (2011)
- John D. States Best Student Paper Award, Association for the Advancement of Automotive Medicine (Faculty Advisor, 2010)
- Best Paper, Roadside Safety, TRB 89th Annual Meeting, AFB20 Roadside Safety Design Committee (2010)
- SAE Award for Excellence in Oral Presentation at the 2010 SAE World Congress (Faculty Advisor, 2010)
- Faculty Fellow, Virginia Tech College of Engineering (2009)
- Paul E. Torgersen Graduate Research Excellence Award, (Virginia Tech, Faculty Advisor, 2009)
- Biomedical Instrumentation Sciences Symposium First Place Poster Competition (Faculty Advisor, 2009)
- Virginia Tech –Wake Forest University Graduate Student Research Symposium Poster Competition, First Place (Faculty Advisor, 2009)
- Lloyd L. Withrow Distinguished Speaker Award (SAE, 2008)
- International Road Federation, First Prize, Student Research Essay Competition (Faculty Advisor, 2009)
- Paul E. Torgersen Graduate Research Excellence Award, (Virginia Tech, Faculty Advisor, 2008)
- SAE Award for Excellence in Oral Presentation at the 2007 SAE Industry/Government Conference (2007)
- John D. States Best Student Paper Award, Association for the Advancement of Automotive Medicine (Faculty Advisor, 2007)
- Virginia Tech –Wake Forest University Graduate Student Research Symposium Poster Competition, Second Place (Faculty Advisor, 2006)
- John D. States Best Student Paper Award, Association for the Advancement of Automotive Medicine (Faculty Advisor, 2006)
- Biomedical Instrumentation Sciences Symposium Poster Competition (Faculty Advisor, 2006)
- Ralph H. Isbrandt Automotive Safety Engineering Award (SAE, 2005)
- SAE Award for Excellence in Oral Presentation at the 2005 SAE World Congress (2005)
- Ralph R. Teetor Educational Award (SAE, 2003)
- Dwight D. Eisenhower Faculty Fellowship (FHWA, 2001)
- ASME Outstanding Student Section Advisor Award – Region III (2003, 2004)
- ASME Outstanding Student Section Advisor Award – Philadelphia Chapter (2000, 2001, 2002)

- Rowan University “Teaching Wall of Fame” Award (2002, 2003, 2005)
- SAE Award for Excellence in Oral Presentation at the 1997 SAE Government/Industry Meeting (1997)
- Luigi Crocco Teaching Prize (Princeton University, 1995)
- Guggenheim Fellowship (Princeton University, 1992)
- Virginia Governor’s Fellowship (University of Virginia, 1979)
- Sigma Xi
- Tau Beta Pi

RESEARCH INTERESTS

Vehicle Crashworthiness, Event Data Recorders, Roadside Safety Features, Vehicle Active Safety Technologies, Crash Modeling and Simulation, Injury Biomechanics, Crash Reconstruction Methodologies

BOOKS

- Gabler HC, Hinch J, and Steiner J, *Event Data Recorders: A Decade of Innovation,* SAE International, Warrendale, PA (2008)

JOURNAL PUBLICATIONS

1. Kusano KD, Sherony R, and Gabler HC, “Advanced Event Data Recorders to Reconstruct Vehicle Trajectories for use in Safety Impact Methodologies (SIM)”, *Traffic Injury Prevention* (in press, available online, June 2013), DOI: 10.1080/15389588.2013.796374.
2. Kusano, K. and Gabler, H., "Characterization of Lane Departure Crashes Using Event Data Recorders Extracted from Real-World Collisions," *SAE International Journal Passenger. Cars - Mechanical Systems* 6(2):2013, doi: 10.4271/2013-01-0730.
3. Tsoi, A., Hinch, J., Ruth, R. and Gabler, H., "Validation of Event Data Recorders in High Severity Full-Frontal Crash Tests," *SAE International Journal of Transportation Safety* 1(1):2013, doi: 10.4271/2013-01-1265.
4. Hampton CE and Gabler HC, “Development of a Missing Post Guideline for Longitudinal Barrier Crash Safety”, *Journal of Transportation Engineering*, v. 139, no.6, pp. 549-555 (2013)
5. Daniello A, Cristino D, and Gabler HC, “Relationship Between Rider Trajectory and Injury Outcome in Motorcycle-Barrier Crashes”, *Transportation Research Record: Journal of the Transportation Research Board,* Transportation Research Board of the National Academies (accepted)
6. Johnson NS and Gabler HC, “Injury Risk due to Side Impact of Non-Tracking Vehicles into Guardrail”, *Transportation Research Record: Journal of the Transportation Research Board,* Transportation Research Board of the National Academies (accepted)
7. Kusano KD and Gabler HC, “Characterization of Opposite-Direction Lane Departure Crashes in the United States”, *Transportation Research Record: Journal of the Transportation Research Board,* Transportation Research Board of the National Academies (accepted)
8. Kusano KD, Kusano SM, and Gabler HC, “Automated Crash Notification Algorithms: Evaluation of In-Vehicle Principal Direction of Force (PDOF)

Estimations", *Transportation Research Part C,* DOI 10.1016/j.trc.2012.09.005 Volume 32, July 2013, Pages 116–128.
9. Daniello A and Gabler HC, "The Characteristics of Injuries in Motorcycle to Barrier Collisions in Maryland", *Transportation Research Record: Journal of the Transportation Research Board,* Transportation Research Board of the National Academies, pp. 92-98, doi 10.3141/2281-12 (2012)
10. Kusano KD and Gabler HC, "Safety Benefits of Forward Collision Warning, Brake Assist, and Autonomous Braking Systems in Rear-end Collisions", *IEEE Transactions – Intelligent Transportation Systems,* 13(4), pp. 1546 – 1555, doi 10.1109/TITS.2012.2191542 (2012)
11. Donoughe K, Whitestone J and Gabler HC, "Analysis of Firetruck Crashes and Associated Firefighter Injuries in the United States", *Annals of Advances in Automotive Medicine,* v.56, pp. 69-76 (2012)
12. Kusano KD and Gabler HC, "Field Relevance of the New Car Assessment Program Lane Departure Warning Confirmation Test," *SAE International Journal Passenger Cars - Mechanical Systems*, 5(1), doi:10.4271/2012-01-0284 (2012)
13. Hampton CE and Gabler HC, "Crash Performance of Strong-Post W-Beam Guardrail with Missing Blockouts", *International Journal of Crashworthiness*, v. 17, no.1, pp. 93-103 (2012)
14. Johnson NS and Gabler HC, "Accuracy of a Damage-Based Reconstruction Method in NHTSA Side Crash Tests", *Traffic Injury Prevention,* v.13, no. 1, pp. 72-80 (2012)
15. Kusano K and Gabler HC, "Method for Estimating Time to Collision at Braking in Real-world, Lead Vehicle Stopped Rear-end Crashes for Use in Pre-crash System Design", *SAE Transactions, Journal of Passenger Car - Mechanical Systems*, SAE Paper No. 2011-01-0576, v. 4 no. 1, pp. 435-443 (2011)
16. Daniello A and Gabler HC, "The Effect of Barrier Type on Injury Severity in Motorcycle to Barrier Collisions in North Carolina, Texas, and New Jersey", *Transportation Research Record: Journal of the Transportation Research Board, No. 2262,* Transportation Research Board of the National Academies, pp. 144–151 (2011)
17. Daniello AL and Gabler HC, "Fatality Risk in Motorcycle Collisions with Roadside Objects in the United States", *Accident Analysis and Prevention*, v.43, pp. 1167–1170 (2011)
18. Daniello A, Swanseen K, Mehta Y, and Gabler HC, "Rating Roads for Motorcyclist Safety: Development of a Motorcycle Road Assessment Program", *Transportation Research Record: Journal of the Transportation Research Board, No. 2194,* Transportation Research Board of the National Academies, pp. 67-74 (2010)
19. Hampton CE, Gabauer DJ, and Gabler HC, "Limits of Acceptable Rail and Post Deflection in Crash-Damaged Strong-Post W-Beam Guardrail", *Transportation Research Record: Journal of the Transportation Research Board, No. 2195,* Transportation Research Board of the National Academies, pp. 95-105 (2010)
20. Kusano KD and Gabler HC, "Potential Occupant Injury Reduction in Pre-Crash System Equipped Vehicles in the Striking Vehicle of Rear-end Crashes", *Annals of Advances in Automotive Medicine,* v.54, pp. 203-214 (2010)

21. Hampton CE and Gabler HC, “Evaluation of the Accuracy of NASS/CDS Delta-V Estimates from the Enhanced WinSmash Algorithm”, *Annals of Advances in Automotive Medicine,* v.54, pp. 241-252 (2010)
22. Thor CP and Gabler HC, “Assessing the Residual Teen Crash Risk Factors after Graduated Driver’s License Implementation”, *Annals of Advances in Automotive Medicine,* v.54, pp. 295-308 (2010)
23. Gabauer DJ, Kusano KD, Marzougui D, Opiela K, Hargrave M, Gabler HC, ”Pendulum Testing as a Means of Assessing the Crash Performance of Longitudinal Barrier with Minor Damage”, *International Journal of Impact Engineering, v.*37, p. 1121-1137 (2010)
24. Gabauer DJ and Gabler HC,” The Effects of Airbags and Seatbelts on Occupant Injury in Longitudinal Barrier Crashes”, *Journal of Safety Research*, v.41, pp. 9-15, (2010).
25. Daniello A, Gabler HC, and Mehta Y, “The Effectiveness of Motorcycle Training and Licensing”, *Transportation Research Record: Journal of the Transportation Research Board, No. 2140,* Transportation Research Board of the National Academies, pp. 206–213, Washington, DC (2009)
26. Gabauer DJ and Gabler HC, “Differential Rollover Risk in Vehicle-to-Traffic Barrier Collisions”, *Annals of Advances in Automotive Medicine,* v.53, pp. 131-140 (2009)
27. Hampton CE and Gabler HC, “NASS/CDS Delta-V Estimates: The Influence of Enhancements to the WinSmash Crash Reconstruction Code”, *Annals of Advances in Automotive Medicine,* v.53, pp. 91-102 (2009)
28. Kemper AR, Stitzel JD, McNally C, Gabler HC, Duma SM, “Biomechanical Response of the Human Clavicle: The Effects of Loading Direction on Bending Properties”, *Journal of Applied Biomechanics*, v.25, no. 2: pp. 165-74 (2009)
29. Gabauer DJ and Gabler HC, “Evaluation of Current Repair Criteria for Longitudinal Barrier with Crash Damage”, *Journal of Transportation Engineering,* Vol. 135, No. 4, pp. 255-234 (2009)
30. Gayzik FS, Martin RS, Gabler HC, Hoth JJ, Duma SM, Meredith JW, and Stitzel JD “Characterization of crash induced thoracic loading resulting in pulmonary contusion”, *Journal of Trauma*; 66(3) p. 840-849 (2009)
31. Gabler HC and Hinch J, “Evaluation of Advanced Air Bag Deployment Algorithm Performance using Event Data Recorders”, *Annals of Advances in Automotive Medicine*, v.52, pp. 175-184 (2008)
32. Gabauer DJ and Gabler HC, “Can Delta-V be Adjusted with Structural and Occupant Restraint Performance to Improve Prediction of Chest Acceleration?”, *Annals of Advances in Automotive Medicine*, v.52, pp. 165-174 (2008)
33. Funk JR, Cormier JM and Gabler HC, “Effect of Delta-V Errors in NASS on Frontal Crash Risk Calculation”, *Annals of Advances in Automotive Medicine*, v.52, pp. 155-164 (2008)
34. Bostrom O, Gabler HC, Digges K, Fildes B, and Sunnevang S, “Injury Reduction Opportunities of Far Side Impact Countermeasures”, *Annals of Advances in Automotive Medicine*, v.52, pp. 289-300 (2008)
35. Gabauer DJ, and Gabler HC, “Comparison of Roadside and Vehicle Crash Test Injury Criteria in Frontal Crash Tests”, *Int. J. Vehicle Safety*, Vol. 3, No. 2, pp.135–148 (2008)

36. Newland C, Belcher T, Bostrom O, Gabler HC, Cha JG, Wong HL, Tylko S, and Nevo RD "Occupant-to-Occupant Interaction and Impact Injury Risk in Side Impact Crashes", *Stapp Car Crash Journal* (2008)
37. Gabauer DJ and Gabler HC, "Comparison of Roadside Crash Injury Metrics Using Event Data Recorders", *Accident Analysis and Prevention,* Vol. 40/2 pp 548-558 (2008)
38. Gabler HC, Digges K, Fildes BN, and Sparke L, "Side Impact Injury Risk for Belted Far Side Passenger Vehicle Occupants", *SAE Transactions, Journal of Passenger Car - Mechanical Systems*, v.114, Section 6, Paper No. 2005-01-0287 (2005)
39. Gabauer DJ and Gabler HC, "Evaluation of Acceleration Severity Index Threshold Values Using Event Data Recorder Technology", *Transportation Research Record: Journal of the Transportation Research Board, No. 1904,* Transportation Research Board of the National Academies, pp. 37-45, Washington, DC (2005)
40. Gabauer DJ and Gabler HC, "A Methodology to Evaluate the Flail Space Model Using Event Data Recorder Technology," *Transportation Research Record: Journal of the Transportation Research Board, No. 1890,* Transportation Research Board of the National Academies, pp.49-57, Washington, DC (2004)
41. Lefler DE and Gabler, H.C., "The Fatality and Injury Risk of Light Truck Impacts with Pedestrians in the United States", *Accident Analysis and Prevention*, v.36, pp. 295-304, Elsevier (2004)
42. Bowen, D., and Gabler, H.C., "Modeling of Commuter Category Aircraft Seats Under Crash Loading", *SAE Transactions, Journal of Aerospace*, v.112, Sec. 1, Paper No. 2003-01-3028 (2003)
43. Gabler, H.C., "The Evolution of Side Crash Compatibility Between Cars, Light Trucks and Vans", *SAE Transactions, Journal of Passenger Car - Mechanical Systems*, v.112, sec. 6, Paper No. 2003-01-0899 (2003)
44. Gabler, H.C. and Hollowell, W.T., "The Crash Compatibility of Cars and Light Trucks*", Crash Prevention and Injury Control*, v.2, No. 1, pp 19-31 (2000)
45. Glassman, I., Yetter, R., and Gabler, H.C., "Asymmetric Whirl Combustion: A New Low NOx Approach", *Proceedings of the Combustion Institute*, 28 (1), pp. 1265-1271 (July 2000)
46. Gabler, H.C. and Hollowell, W.T.," The Aggressivity of Light Trucks and Vans in Traffic Crashes", *SAE Transactions, Journal of Passenger Cars*, Section 6, v.107, Paper No. 980908 (1998)
47. Trella, T., Gabler, H.C., Kanianthra, J.N., and Wagner, J., "Side Impact Crashworthiness Design: Evaluation of Padding Characteristics through Mathematical Simulations." *SAE Transactions, Journal of Passenger Cars*, Section 6, v.100, Paper No. 912900 (1991)
48. White, K.P., Jr., Pilkey, W.D., and Gabler, H.C., "Approximating dynamic response in small arrays using polynomial parameterizations and response surface methodology," *Shock and Vibration Bulletin*, Bulletin 55 (June 1985)
49. White, K.P., Jr., Pilkey, W.D., Gabler, H.C., and Hollowell, T., "Simulation optimization of the crashworthiness of a passenger vehicle in frontal collisions using response surface methodology," SAE Paper 850512, *SAE Transactions, Journal of Passenger Cars*, Section 6, (1985)

50. White, K.P., Jr., Pilkey, W.D., Gabler, H.C., and Hollowell, T., "Minimizing Injuries in Frontal Collisions using the SSOM," *Structural Impact and Crashworthiness*, V.2, Elsevier, New York, pp. 757-770 (1984)
51. White, K.P., Jr., Pilkey, W.D., Gabler, H.C., and Hollowell, T., "A Computer-Aided Design Tool for Automobile Safety: Overview of the Safety Model," *Large-Scale Systems in Information and Decision Technologies: Theory and Applications*, Vol. 4, No. 4, pp. 245-262 (1983)
52. White, K.P., Jr., Pilkey, W.D., Gabler, H.C., and Hollowell, T., "Optimizing Design Parameters for Highway Vehicle Safety," *International Journal of Vehicle Design*, V. 4, No. 6, pp. 618-632 (1983)

CONFERENCE PROCEEDINGS

1. Kusano KD and Gabler HC, "Comparison of Logistic Regression and Ensemble Machine Learning Algorithms Injury Risk Models for Advanced Automated Crash Notification Algorithms", *Proceedings of the 2013 Road Safety and Simulation International Conference*, Rome, Italy (to be presented October 2013)
2. Kusano KD and Gabler HC, "Driver Response to Road Departures in the 100-Car Naturalistic Study", *Proceedings of the 2013 Road Safety and Simulation International Conference*, Rome, Italy (to be presented October 2013)
3. Gorman TI, Kusano KD, and Gabler HC, "Model of Fleet-wide Safety Benefits of Lane Departure Warning Systems", *Proceedings of the 2013 IEEE Intelligent Transportation Systems Conference*, The Hague, Netherlands (to be presented October 2013)
4. Kusano KD, Daniello AL, and Gabler HC, "Evaluation of Driver Model for Lane Departure Warning Benefits Estimates", *Proceedings of the Second International Symposium on Future Active Safety Technology toward Zero-Traffic-Accidents*, Nagoya, Japan (to be presented September 2013)
5. Gorman TI, Kusano KD, and Gabler HC, "Mathematical Model of Road Departure Events and Estimates of Lane Departure Warning Benefits", *Proceedings of the Second International Symposium on Future Active Safety Technology toward Zero-Traffic-Accidents*, Nagoya, Japan (to be presented September 2013)
6. Chen R and Gabler HC, "Incidence and Risk of Direct Steering Wheel Impact in Vehicles Equipped with Advanced Air Bags", *Proceedings of the Twenty-Third International Conference on Enhanced Safety of Vehicles*, Paper Number 13-0463, Seoul, Korea (May 2013)
7. Kusano KD and Gabler HC, "Pre-crash Scenarios for Determining Target Populations of Active Safety Systems", *Proceedings of the Twenty-Third International Conference on Enhanced Safety of Vehicles*, Paper Number 13-0078, Seoul, Korea (May 2013)
8. Johnson NS, Gabler HC, and Sharma D, "Preliminary Evaluation of NASS-CDS Side Crash Delta-V Estimates using Event Data Recorders", *Proceedings of the Twenty-Third International Conference on Enhanced Safety of Vehicles*, Paper Number 13-0240, Seoul, Korea (May 2013)
9. Kusano KD and Gabler HC, "Characterization of Lane Departure Crashes using Event Data Recorders Extracted from Real-world Collisions", SAE Paper 2013-01-0730 (April 2013)

10. Daniello AL, Kusano KD and Gabler HC, “Validation of a Driver Recovery Model Using Real-World Road Departure Cases”, SAE Paper 2013-01-0723 (April 2013)
11. Tsoi A, Hinch J, Ruth R, and Gabler HC, “Validation of Event Data Recorders in High Severity Full-Frontal Crash Tests”, SAE Paper 2013-01-1265 (April 2013)
12. Gabler HC, “Building a Remote Collaborative Learning Course in Computational Modeling of Car Crash Injury Prevention”, *Proceedings of the Eighth International Conference on Computer Science & Education*, Colombo, Sri Lanka (April 2013)
13. Daniello A, Cristino D, and Gabler HC, “Relationship Between Rider Trajectory and Injury Outcome in Motorcycle-Barrier Crashes”, *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Paper No. 13-2184, Washington, DC (January 2013)
14. Kusano KD and Gabler HC, “Characterization of Opposite-Direction Lane Departure Crashes in the United States”, *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Paper No. 13-3805, Washington, DC (January 2013)
15. Johnson NS and Gabler HC, “Injury Risk due to Side Impact of Non-Tracking Vehicles into Guardrail”, *Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Paper No. 13-4694, Washington, DC (January 2013)
16. Kusano KD and Gabler HC, “Model of Collision Avoidance with Lane Departure Warning in Real-world Departure Collisions with Fixed Roadside Objects", *Proceedings of the 2012 IEEE Intelligent Transportation Systems Conference*, Anchorage, Alaska (September 2012)
17. Kusano KD and Gabler HC, “Identification of Target Populations for Current Active Safety Systems using Driver Behavior”, *Proceedings of the 2012 IEEE Intelligent Vehicle Symposium*, Alcalá de Henares, Spain (June 2012)
18. Daniello A and Gabler HC, “The Characteristics of Injuries in Motorcycle to Barrier Collisions in Maryland”, *Proceedings of the 91st Annual Meeting of the Transportation Research Board,* Paper No. 12-2753, Washington, DC (January 2012)
19. Kusano KD and Gabler HC, “Rural Road Departure Crashes: Why is Injury Severity Correlated with Lane Markings?”, *Proceedings of the 91st Annual Meeting of the Transportation Research Board,* Paper No. 12-1915, Washington, DC (January 2012)
20. Kusano KD and Gabler HC, “Injury Mitigation in the Collision Partners of Pre-collision System equipped Vehicles in Rear-end Collisions", *Proceedings of the 2011 IEEE Intelligent Transportation Systems Conference,* Washington, DC (October 2011)
21. Kusano KD and Gabler HC, “On-Scene Determination of Driver Crash Causation and Avoidance Maneuvers in Rear-End Collisions", *Proceedings of the Third TRB International Conference on Road Safety and Simulation*, Indianapolis, IN (September 2011)
22. Kusano KD and Gabler HC, “Automated Crash Notification Algorithms: Evaluation of In-Vehicle Principal Direction of Force (PDOF) Estimation Algorithms", *Proceedings of the Third TRB International Conference on Road Safety and Simulation*, Indianapolis, IN (September 2011)

23. Johnson N and Gabler HC, "Evaluation of WinSmash Accuracy in NHTSA Side Crash Test Reconstructions", *Proceedings of the Twenty-Second International Conference on Enhanced Safety of Vehicles*, Paper No. 11-0389, Washington DC (June 2011)
24. Kusano KD and Gabler HC, "Potential Effectiveness of Integrated Forward Collision Warning, Pre-Collision Brake Assist, and Automated Pre-Collision Braking Systems in Real-World, Rear-End Collisions", *Proceedings of the Twenty-Second International Conference on Enhanced Safety of Vehicles*, Paper Number 11-0364, Washington DC (June 2011)
25. Loftis KL, Moreno DP, Tan J, Gabler HC, and Stitzel JD, "Using computed tomography scans for analysis of motorcycle helmets in real-world crashes", *Biomedical Sciences Instrumentation* , v. 47: 234-9 (2011)
26. Kusano K and Gabler HC, "Method for Estimating Time to Collision at Braking in Real-world, Lead Vehicle Stopped Rear-end Crashes for Use in Pre-crash System Design", SAE Paper No. 2011-01-0576 (April 2011)
27. Hampton CE and Gabler HC, "Crash Performance of Strong-Post W-Beam Guardrail with Missing Blockouts", *Proceedings of the 2010 ICRASH Conference*, Paper No. 2010-118, Washington, DC (September 2010)
28. Kusano K and Gabler HC, "Target Population for Injury Reduction from Pre-Crash Systems", SAE Paper No. 2010-01-0463 (April 2010)
29. Loftis K, Martin RS, Gabler HC, Meredith JW, and Stitzel JD, "Development of a Method to Compare Real-World Crashes to Vehicle Crash Tests", SAE Paper No. 2010-01-0147 (April 2010)
30. Hampton CE and Gabler HC, "Crash Performance of Strong-Post W-Beam Guardrail with Missing Posts", *Proceedings of the 89th Annual Meeting of the Transportation Research Board*, Paper No. 10-1589, Washington, DC (January 2010)
31. Gabler HC and Hinch J, "Feasibility of using Event Data Recorders to Characterize the Pre-Crash Behavior of Drivers in Rear-End Collisions", *Proceedings of the Twenty-first International Conference on Enhanced Safety of Vehicles*, Paper No. 09-0452, Stuttgart, Germany (June 2009)
32. Daniello A, Powell B, Schaeffer N, McClinton A, Mehta Y, Swanseen K, and Gabler HC, "Initial Site Inspection of Motorcycle Collisions with Roadside Objects in New Jersey", *Proceedings of the Twenty-first International Conference on Enhanced Safety of Vehicles*, Paper No. 09-0450, Stuttgart, Germany (June 2009)
33. Hampton CE and Gabler HC, "Influence of the Missing Vehicle and CDC only Delta-V Reconstruction Algorithms for Prediction of Occupant Injury Risk", *Biomedical Sciences Instrumentation* 45: pp. 238-43 (2009)
34. Johnson N, Hampton CE, Webster GD, Rzigalinski BA, and Gabler HC, "Validation of an Improved Injury Device for In Vitro Study of Neural Cell Deformation", *Biomedical Sciences Instrumentation* 45: pp. 125-30 (2009)
35. Johnson N, Hampton CE, and Gabler HC, "Evaluation of the Accuracy of Side Impact Crash Test Reconstructions", *Biomedical Sciences Instrumentation* 45: pp. 250-5 (2009)
36. Thor CP and Gabler HC, "Abdominal Injury with Airbag Deployment for Belted Drivers in Frontal Crashes", *Biomedical Sciences Instrumentation* 45: pp. 262-7 (2009)

37. Thor CP and Gabler HC, “The Influence of Airbags on Thoracic Organ Lesion Types”, *Biomedical Sciences Instrumentation* 45: pp. 352-7 (2009)
38. Gabauer DJ and Gabler HC, “Acceleration-Based Occupant injury criteria for predicting injury in real-world crashes”, *Biomedical Sciences Instrumentation* 44, pp. 213-218 (2008)
39. Gabauer DJ and Gabler HC, “Comparison of occupant restraint performance measures for crash injury prediction”, *Biomedical Sciences Instrumentation* 44, pp. 219-224 (2008)
40. Hampton, C.E., Webster, G.D., Rzigalinski, B.A., and Gabler, H.C., “Mechanical Properties of Polytetraflouroethylene Elastomer Membrane for Dynamic Cell Culture Testing”, *Biomedical Sciences Instrumentation* 44, pp. 105-110 (2008)
41. Thor, C.P., Bieryla, K. and Gabler, H.C., “Estimating Shoulder Injury Risk using Low Rate Lateral Impacts to Dummies”, *Biomedical Sciences Instrumentation* 44, pp. 274-279 (2008)
42. Thor, C.P. and Gabler, H.C., “The Relationship between Thoracic Organ Injuries and Associated Rib Fractures”, *Biomedical Sciences Instrumentation* 44, pp. 292-297 (2008)
43. Wang, Q. and Gabler, H.C., “Review of Correlation Methods for Evaluating Finite Element Simulations of Impact Injury Risk”, *Biomedical Sciences Instrumentation* 44, pp. 268-273 (2008)
44. Wang, Q. and Gabler, H.C., “Validation of Finite Element Models of Injury Risk in Vehicle-Roadside Barrier Crashes”, *Biomedical Sciences Instrumentation* 44, pp. 298-303 (2008)
45. Webster, G.D., Rzigalinski, B.A., and Gabler, H.C., “Development of an Improved Injury Device for Neural Cell Cultures”, *Biomedical Sciences Instrumentation* 44, pp. 483-488 (2008)
46. Webster, G.D. and Gabler, H.C., “Modeling of Transdermal Transport of Alcohol: Effect of Body Mass and Gender”, *Biomedical Sciences Instrumentation* 44, pp. 361-366 (2008)
47. Gabauer DJ and Gabler HC, “Review of Current Damage-Level Criteria for Longitudinal Barrier Repair”, *Proceedings of the 87th Annual Meeting of the Transportation Research Record,* Washington, DC (January 2008)
48. Webster, G.D. and Gabler HC, “Feasibility of Transdermal Ethanol Sensing for the Detection of Intoxicated Drivers”, *51st Annual Proceedings of the Association for the Advancement of Automotive Medicine*, Melbourne, Australia (2007)
49. Gabler HC, and Gabauer DJ, “Opportunities for Reduction of Fatalities in Vehicle-Guardrail Collisions”, *51st Annual Proceedings of the Association for the Advancement of Automotive Medicine*, Melbourne, Australia (2007)
50. Stitzel, J.D., ,Kilgo, P., Schmotzer, B., Gabler, H.C. and Meredith, J.W., “A Population-Based Comparison of CIREN and NASS Cases using Similarity Scoring”, *51st Annual Proceedings of the Association for the Advancement of Automotive Medicine*, Melbourne, Australia (2007)
51. Gabler HC and Hinch J, “Characterization of Advanced Air Bag Field Performance using Event Data Recorders”, *Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles*, Paper No. 07-0349, Lyons, France (June 2007)

52. Gabler HC, “The Risk of Fatality in Motorcycle Crashes with Roadside Barriers”, Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles, Paper No. 07-0474, Lyons, France (June 2007)
53. Wang, Q. and Gabler, H.C., “Accuracy of Vehicle Frontal Stiffness Estimates for Crash Reconstuction” , Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles, Paper No. 07-0513, Lyons, France (June 2007)
54. Fildes, B.N., Fitzharris, M., Gabler, H.C., Digges, K., and Smith, S., “Chest and Abdominal Injuries to Occupants in Far Side Crashes”, Proceedings of the Twentieth International Conference on Enhanced Safety of Vehicles, Paper No. 07-0384, Lyons, France (June 2007)
55. Gabauer DJ and Gabler HC, “Occupant Injury in Longitudinal Barrier Collisions: Effects of Restraints”, Biomedical Sciences Instrumentation 43, pp. 1-6 (2007)
56. Thor, C. and Gabler, H.C., “Methodology for Estimating Thoracic Impact Response in Frontal Crash Tests”, Biomedical Sciences Instrumentation 43, pp. 336-341 (2007)
57. Webster, G. and Gabler, H.C., “Assessment of Dermal Ethanol Emission Sensors: Experimental Design”, Biomedical Sciences Instrumentation 43, pp. 348-353 (2007)
58. Gabler HC, “The Emerging Risk of Fatal Motorcycle Crashes with Guardrails”, Proceedings of the 86th Annual Meeting of the Transportation Research Record, Washington, DC (January 2007)
59. Gabauer DJ and Gabler HC, “Comparison of Roadside and Vehicle Crash Test Injury Criteria in Frontal Crash Tests”, Proceedings of the 86th Annual Meeting of the Transportation Research Record, Washington, DC (January 2007)
60. Niehoff, P. and Gabler, H.C., “The Accuracy of WinSmash Delta-V Estimates: The Influence of Vehicle Type, Stiffness, and Impact Mode”, Annual Proceedings - Association for the Advancement of Automotive Medicine 2006, pp. 73-89 (October 2006)
61. Gabauer DJ and Gabler HC, “Comparison of Delta-V and Occupant Impact Velocity Crash Severity Metrics using Event Data Recorders”, Annual Proceedings - Association for the Advancement of Automotive Medicine 2006, pp. 57-71 (October 2006)
62. Duma, S., Moorcroft, D.M., Gabler, H.C., Manoogian, S.M., Stitzel, J.D., and Duma G.G., “Analysis of Pregnant Occupant Crash Exposure and the Potential Effectiveness of Four-Point Seatbelts in Far Side Crashes”, Annual Proceedings - Association for the Advancement of Automotive Medicine 2006, pp. 187-198 (October 2006)
63. Gabauer DJ and Gabler HC, “Development of Point Mass Injury Criteria Using Event Data Recorders”, Biomedical Sciences Instrumentation 42, pp. 166-171 (2006)
64. Hampton, C.E., Gabler, H.C., and Rzigalinski, B., “Numerical Simulation of a Cellular-Level Experiment to Induce Traumatic Injury to Neurons”, Biomedical Sciences Instrumentation 42, pp. 205-210 (2006)
65. Kemper A, Stitzel J, Gabler HC, Duma S and Matsuoka F, “Biomechanical response of the human clavicle subjected to dynamic bending”, Biomedical Sciences Instrumentation 42, pp. 231-236 (2006)

66. Digges, K.H. and Gabler, H.C., "Opportunities for Reducing Casualties in Far-side Crashes", SAE Paper No. 2006-01-0450 (April 2006)
67. Fildes, B., Fitzharris, M., Logan, D. and Gabler, H.C., "Side Impact Crashes and Countermeasures", Proceedings of the Fourth International Forum of Automotive Traffic Safety, Changsha, China (October 2005)
68. Digges, K., Gabler, H., Mohan, P., and Alonso, B., "Characteristics of the Injury Environment in Far-Side Crashes", 49th Annual Proceedings of the Association for the Advancement of Automotive Medicine, Boston, MA (September 2005)
69. Gabler, H.C., Fitzharris, M., Scully, J., Fildes, B.N., Digges, K. and Sparke, L., "Far Side Impact Injury Risk for Belted Occupants in Australia and the United States", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Paper No. 05-0420-O, Washington, DC (June 2005)
70. Niehoff, P., Gabler, H.C., Brophy, J. Chidester, A., Hinch, J., and Ragland, C., "Evaluation of Event Data Recorders in Full Systems Crash Tests", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Paper No. 05-0271-O, Washington, DC (June 2005)
71. Fildes, B, Linder, A., Douglas, C., Digges, K., Morgan, R., Pintar, F., Yoganandan, N., Gabler, H., Duma, S., Stitzel, J, Bostrom, O., Sparke, L., Smith, S., and Newland, C., "Occupant Protection in Far Side Crashes", Proceedings of the Nineteenth International Conference on Enhanced Safety of Vehicles, Paper No. 05-0299-O, Washington, DC (June 2005)
72. Gabauer DJ and Gabler HC, "A Comparison of Roadside Crash Test Occupant Risk Criteria Using Event Data Recorder Technology", Proceedings of the 2004 International IRCOBI Conference on the Biomechanics of Impact, Graz, Austria (September 2004)
73. Fildes, B., Gabler, H.C., Otte, D., Linder, A., L. Sparke, L., "Pedestrian Impact Priorities Using Real-World Crash Data and Harm" Proceedings of the 2004 International IRCOBI Conference on the Biomechanics of Impact, Graz, Austria (September 2004)
74. Fildes B., Linder, A., Clark, A., Otte, D., Gabler, H.C., Yang, Y., Fredrikkson, R., Fujita, Y., Cessari, D., Yang, K., Sparke, L., and Smith, S., "Pedestrian Safety: International Collaborative Research Based on Real World Crash Data", Proceedings of the International Expert Symposium on Accident Research (ESAR), Hannover, Germany (September 2004)
75. Gabler, H.C., Hampton, C.E., and Hinch, J., "Crash Severity: A Comparison of Event Data Recorder Measurements with Accident Reconstruction Estimates", SAE Paper No. 2004-01-1194 (March 2004)
76. Gabler, H.C., Browning, D., and Schmalzel, J., "Development of an Enhanced Emergency Locator Transmitter for General Aviation", Proceedings of the 2003 SAE World Aviation Congress, Paper No. 2003-01-3010, Montreal, Canada (September 2003)
77. Gabler, H.C., Hampton, C., and Roston, T., "Estimating Crash Severity: Can Event Data Recorders Replace Crash Reconstruction?" Proceedings of the Eighteenth International Conference on Enhanced Safety of Vehicles, Paper No. 490, Nagoya, Japan. (May 2003)
78. Gabler, H.C., DeFuria, J., and Schmalzel, J.L., "Automated Crash Notification via the Wireless Web: Design and Validation", Proceedings of the Seventeenth

International Conference on Enhanced Safety of Vehicles, Paper No. 71, Amsterdam, Netherlands (June 2001)
79. Lefler, D.E. and Gabler, H.C., "The Emerging Threat of Light Truck Impact with Pedestrians", Proceedings of the Seventeenth International Conference on Enhanced Safety of Vehicles, Paper No. 212, Amsterdam, Netherlands (June 2001)
80. Chandrupatla T.R., Chen, J. C., Constans, E., Gabler, H. C., Kadlowec, J., Marchese, A. J., von Lockette, P. and Zhang, H. (2001). "Engineering Clinics: Integrating Design throughout the ME Curriculum". Proceedings of the 2001 ASME International Mechanical Engineering Congress and Exposition, New York, NY (November 2001)
81. Ramachandran, R.P., Chen, J.C., Head, L.M., Schmalzel, J.L.and, Gabler, H.C., Automatic compact disc transfer for quality assurance testing, Proceedings - Frontiers in Education Conference 2001 (2001)
82. Gabler, H.C., Krchnavek. R., and Schmalzel, J., "Development of an Automated Crash Notification System: An Undergraduate Research Experience", Frontiers in Engineering Education 2000, Kansas City, Mo. (October 2000)
83. Fildes, B.N., Gabler, H.C., Fitzharris, M., and Morris, A.P., "Determining Side Impact Priorities Using Real-World Crash Data and Harm", Proceedings of the 2000 International IRCOBI Conference on the Biomechanics of Impact (October 2000)
84. Constans, E. and Gabler, H.C., "Coupling Thermodynamics and Mechanical Design in a Cross-Curricular Undergraduate Design Project", Frontiers in Engineering Education 2000, Kansas City, Mo. (October 2000)
85. Gabler, H.C., Fildes, B.N., and Fitzharris, M., "Improved Side Impact Protection: A Search for Systems Modeling Priorities", 2000 ASME Design Automation Conference, Baltimore, MD (September 2000)
86. Constans, E. and Gabler, H.C., "The Compressor project: Coupling Thermodynamics and Mechanical Design in a Cross-Curricular Project", ASEE Mid-Atlantic Spring 2000 Conference, Farmington, NY. (April 2000)
87. Gabler, H.C. and Fildes, B. N., "Car Crash Compatibility: The Prospects for International Harmonization", Society of Automotive Engineers Paper No. 1999-01-0069, SAE Special Publication SP-1442, "Vehicle Aggressivity and Compatibility in Automotive Crashes" (March 1999)
88. Gabler, H.C. and Hollowell, W.T., "NHTSA's Vehicle Aggressivity and Compatibility Research Program", Proceedings of the Sixteenth International Conference on Enhanced Safety Vehicles, Windsor, Canada (June 1998)
89. Gabler, H.C. Yetter, R., and Glassman, I. "Asymmetric Whirl Combustion: A New Approach for Non-Premixed Low NOx Gas Turbine Combustor Design," Proceedings of the 34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference, Cleveland (July 1998)
90. Hollowell, W.T. and Gabler, H.C. "The NHTSA Vehicle Impact Aggressivity Research Program", Proceedings of the Fifteenth International Conference on Enhanced Safety Vehicles, Melbourne, Australia (May 1996)
91. Gabler, H.C., Yetter, R., and Glassman, I. "A Numerical Investigation of Asymmetric and Symmetric Fuel Injection in Whirl Flames", Proceedings of the 1996 Fall Technical Meeting of the Eastern States Section of the Combustion Institute, Hilton Head, SC (1996)

92. Glassman, I., Yetter, R., Gabler, H.C., and Sivo, J., “Asymmetric Whirl Combustion: A New Phenomenon?”, Proceedings of the 1994 Fall Technical Meeting of the Eastern States Section of the Combustion Institute, Clearwater, FL (1994)
93. Gabler, H.C., Hollowell, W.T., and Hitchcock, R., “Systems Optimization of Vehicle Crashworthiness” Proceedings of the Fourteenth International Conference on Enhanced Safety Vehicles, Munich, Germany (May 1994)
94. Kirkpatrick, S.W., Holmes, B.S., Hollowell, W.T., Gabler, H.C., and Trella, T.J., “Finite Element Modeling of the Side Impact Dummy (SID)” Human Surrogates: Design, Development and Side Impact Protection, SAE SP-945, SAE No. 930104. (March 1993)
95. Kanianthra JN, Willke DT, Gabler HC and Zuby DS, “Comparison of the BioSID, EuroSID, and SID Side Impact Dummies in Lateral, Pendulum, Sled, and Car Impacts”, Proceedings of the Thirteenth International Conference on Experimental Safety Vehicles, Paper S5-O-16, Paris, France. (November 1991)
96. Gabler, HC, Willke DT, and Wagner JJ, “Upper Interior Head Impacts: The Safety Performance of Passenger Vehicles”. Proceedings of the Thirteenth International Conference on Experimental Safety Vehicles, Paper S9-0-7, Paris, France (November 1991)
97. DiMasi, F., Eppinger, R.H., Gabler, H.C., and Marcus, J.H., “Simulated Head Impacts with Upper Interior Surfaces Using Rigid and Anatomic Brain Models.” Auto and Track Safety, NHTSA Technical Journal, (Summer 1991)
98. Willke, D.T. and Gabler, H.C., “Upper Interior Head Protection: A Fleetwide Characterization”. Proceedings of the Twelfth International Conference on Experimental Safety Vehicles, Gotenborg, Sweden. (May 1989)
99. Gabler, H.C., III, Hackney, J.R., and Hollowell, W.T., “DEPTH: A Relationship between Side Impact Thoracic Injury and Vehicle Design”. Proceedings of the Twelfth International Conference on Experimental Safety Vehicles, Gotenborg, Sweden. (May 1989)
100. Monk, M.W., Gabler, H.C., and Sullivan, L.K., “Subsystem Testing for Head to Upper Interior Safety”, Proceedings of the Eleventh International Conference on Experimental Safety Vehicles, Washington, D.C. (May 1987)
101. Hackney, J.R., Gabler, H.C., Kanianthra, J.N., and Cohen, D.S., “Update of the NHTSA Research Activity in Thoracic Side Impact Protection for the Front Seat Occupant”, Proceedings of the 31st Stapp Car Crash Conference, SAE Paper 872207 (November 1987)
102. Gabler, H.C. and Marcus, J.H., “IGOR: An Expert Support System for the Classification of Crash Victim Trauma”, Proceedings of the IEEE Second Annual Conference on Expert Systems in Government, Washington, DC. (March 1986)
103. Gabler, H.C., III and Hackney, J.R., “The Safety Performance of Production Vehicles in Side Impact”, Proceedings of the Tenth International Conference on Experimental Safety Vehicles, Oxford, England. (July 1985)
104. Gabler, H.C. and Stevens, D.M., “A System for Automated Diagnosis of Reactor Coolant Pumps," Proceedings of the Fifth Power Plant Dynamics, Control, and Testing Symposium, Knoxville, Tennessee. (March 1983)
105. White, K.P., Jr., Pilkey, W.D., Gabler, H.C., and Hollowell, T., “The Safety Systems Optimization Model," Proceedings of the Fourth International Symposium on Large Engineering Systems (June 1982)

ABSTRACTS AND OTHER CONFERENCE PROCEEDINGS

1. Daniello AL and Gabler HC, "Relationship between Collision Mode and Injury Outcome in Motorcyle-to-Barrier Crashes", *56th Annual Proceedings of the Association for the Advancement of Automotive Medicine, Student Symposium, Seattle, WA (October 2012)*
2. Tsoi A, Hinch J, and Gabler HC, "Analysis of Event Data Recorder Survivability in Crashes Involving Fire and Immersion", *56th Annual Proceedings of the Association for the Advancement of Automotive Medicine, Student Symposium, Seattle, WA (October 2012)*
3. Sandberg LM and Gabler HC, "Injury Risk to Children Exposed to Low Risk Deployment of Advanced Airbags", *Proceedings of the 2012 Biomedical Engineering Society Conference* (October 2012)
4. Daniello AL and Gabler HC, "Motorcyclist Fatality Risk: the Influence of Collision Partner Body Style", *Proceedings of the 2012 Biomedical Engineering Society Conference* (October 2012)
5. Daniello AL and Gabler HC, "Using Propensity Score to Link Crash Databases", *Proceedings of the 2012 Biomedical Engineering Society Conference* (October 2012)
6. Tsoi A, Kusano KD and Gabler HC, "Advanced Algorithms for Telemetry-Based Triage of Crash Injuries", *Proceedings of the 2012 Biomedical Engineering Society Conference* (October 2012)
7. Kusano KD and Gabler HC, "Quantitative Crash Injury Risk Predictions by Body Region: Is Risk Sensitive to New Vehicle Safety Features?" *Proceedings of the ASME 2012 Summer Bioengineering Conference*, Paper No. SBC2012-80301, Fajardo, Puerto Rico (June 2012)
8. Daniello AL, Stitzel J, and Gabler HC, "Evaluation of Injury Causation in Motorcycle-Barrier Crashes: A Clinical Study", *Proceedings of the 2011 Biomedical Engineering Society Conference,* (October 2011)
9. Kusano S and Gabler HC, "Modeling the Influence of Stomach Contents on Alcohol Elimination Rate", *Proceedings of the 2011 Biomedical Engineering Society Conference,* (October 2011)
10. Fry B, Kim S, Fry W, and Gabler HC, "The Correlation between Rib Fractures and Pulmonary Contusions", *Proceedings of the 2010 Biomedical Engineering Society Conference,* (October 2010)
11. Comas S and Gabler HC, "Feasibility of Enhanced Algorithms for Post-Crash Injury Prediction for Improved Field Triage", *Proceedings of the 2010 Biomedical Engineering Society Conference,* (October 2010)
12. Kusano S and Gabler HC, "Examination of Factors Which Lead to Over- and Under-Triage of Trauma Victims", *54th Annual Proceedings of the Association for the Advancement of Automotive Medicine, Student Symposium*, Las Vegas, NV (October 2010)
13. Kusano KD and Gabler HC, "The Effectiveness of Pre-Crash Systems (PCS) to Reduce Traumatic Injury in Passenger Vehicle Rear-end Collisions", 2010 ICTAS Research Symposium, The Institute for Critical Technology and Applied Science at Virginia Tech (September 2010)
14. Johnson N, Hampton CE, Rzigalinski BA, Hardy W, and Gabler HC, "Evaluation of an In-Vitro Injury Device for Studying Neural Cell Injury Response to High-

Rate Loading", 2010 ICTAS Research Symposium, The Institute for Critical Technology and Applied Science at Virginia Tech (September 2010)

15. Daniello A and Gabler HC, "Fatality Risk in Single- and Multi- Event Motorcycle Collisions with Roadside Objects in the United States", 2010 ICTAS Research Symposium, The Institute for Critical Technology and Applied Science at Virginia Tech (September 2010)
16. Kim ES and Gabler HC, "The Correlation between Rib Fractures and Pulmonary Contusions", 2010 ICTAS Research Symposium, The Institute for Critical Technology and Applied Science at Virginia Tech (September 2010)
17. Johnson N, Hampton CE, Rzigalinski BA, Hardy W, and Gabler HC, "Development of a Device for In Vitro Study of Astrocytes Subjected to Simulated Blast Over Pressure Loading", *Proceedings of the 2009 Biomedical Engineering Society Conference,* PS-9B-149 (2009)
18. Johnson N and Gabler HC, "Accuracy of Side Impact Delta-V Estimations using Vehicle-Specific Stiffness Coefficients in WinSmash", Poster Presentation at the *51st Annual Proceedings of the Association for the Advancement of Automotive Medicine*, Baltimore, MD (2009)
19. Hampton CE, Johnson N, Rzigalinski BA, Hardy W, and Gabler HC, "Numerical Investigation of the Mechanical Response of Astrocyte Cultures Subjected to Blast Overpressure Loading ", *Proceedings of the 2009 Biomedical Engineering Society Conference,* PS-9A-184 (2009)
20. Johnson N and Gabler HC, "Enhanced Reconstruction Methods for Determining Side Impact Injury Risk", 6th Annual Injury Biomechanics Symposium, Ohio State University (2010)
21. Gabauer DJ and Gabler HC, "Correlating Delta-V to Occupant Injury using Event Data Recorders", *Proceedings of the American Society of Biomechanics 2006 Annual Meeting*, Blacksburg, VA (September 2006)
22. Hampton, C.E., Gabler, H.C., and Rzigalinski, B., "Evaluation of Two Methods to Induce Mechanical Injury to Neuronal Cell Cultures", *Proceedings of the American Society of Biomechanics 2006 Annual Meeting*, Blacksburg, VA (September 2006)
23. Gabler, H.C., Fildes, B., Fitzharris, M., and Digges, K.H., "The Incidence of Upper and Lower Extremity Injuries from Far Side Crashes", *Proceedings of the Fifth World Congress of Biomechanics*, Munich, Germany (July 2006)
24. Fildes, B., Gabler, H.C., Digges, K.H., and Fitzharris, M., "Thoracic Injuries in Far-Side Crashes", *Proceedings of the Fifth World Congress of Biomechanics*, Munich, Germany (July 2006)
25. Gabauer, D.J., Gabler, H.C., and Thomson, R., "Methodology for Evaluation of Impact Injury Criteria using Real Crash Injury Outcomes and Event Data Recorders", *Proceedings of the Fifth World Congress of Biomechanics*, Munich, Germany (July 2006)

TECHNICAL REPORTS

1. Gabler HC, Kusano KD, Kusano S, Daniello A, and Johnson N, "Feasibility of using Event Data Recorders to Improve Post-Crash Triage Decisions and Identify Vehicle Rollover Crash Characteristics: Final Report", Report to the U.S. National Highway Traffic Safety Administration (publication expected May 2012)

2. Gabler HC, Hampton CE, and Johnson N, “Development of the WinSMASH 2010 Crash Reconstruction Code: Final Report”, Report to the U.S. National Highway Traffic Safety Administration, DOT HS 811 546 (July 2012)
3. Gabler HC and Kusano KD, “Pre-Crash System Safety Benefits Estimation”, Final Report to Toyota Motor Company (May 2011)
4. Gabler HC and Litowitz J, “Evaluation of Toyota Event Data Recorders in Frontal Crash Tests”, Report to the U.S. National Highway Traffic Safety Administration (February 2011)
5. Gabler, H.C., Gabauer, D.J., Daniello, A., Wang, C., and McGinnis, R., “Factors Related to Serious Injury and Fatal Motorcycle Crashes with Traffic Barriers, Interim Report”, Report to the Transportation Research Board, National Academies of Science, NCHRP Project 22-26 (April 2010)
6. Gabler, H.C., Thor, C.P., and Hinch J., “Preliminary Evaluation of Advanced Air Bag Field Performance Using Event Data Recorders”, U.S. Department of Transportation, Research and Innovative Technology Administration, DOT HS 811 015 (August 2008)
7. Mehta, Y, Gabler HC, Daniello A and Swanseen K, “New Jersey Motorcycle Fatality Rates, Final Report”, Report to the New Jersey Department of Transportation, FHWA-NJ-2010-003 (2010)
8. Mehta, Y and Gabler, H.C., “Analysis of Fatal Accidents in New Jersey”, Report to the New Jersey Department of Transportation, FHWA-NJ-2008-05 (June 2008)
9. Gabler, H.C., Gabauer, D.J., and Riddell, W.T., “Breakaway Utility Poles: Feasibility of Energy Absorbing Utility Pole Installations in New Jersey – Final Report”, Report to the New Jersey Department of Transportation, FHWA-NJ-2007-018 (December 2007)
10. Gabler, H.C., Gabauer, D.J. and Wu, W., “Criteria for Restoration of Longitudinal Barriers, Interim Report”, Report to the Transportation Research Board, National Academies of Science, NCHRP Project 22-23 (April 2007)
11. Gabler, H.C. and Gabauer, D.J., “Safety Audit of Fatalities and Injuries Involving Guide Rail, Final Report”, Report to the New Jersey Department of Transportation, FHWA-NJ-2007-001 (December 2006)
12. Gabler, H.C. and Molnar, C., “Development of an Enhanced Emergency Locator Transmitter for General Aviation, Final Report”, Report to the New Jersey Department of Transportation, FHWA-NJ-2006-013 (September 2006)
13. Gabler, H.C. and Niehoff, P., “Use of Event Data Recorder Data to Support Delta-V Estimation, Final Report”, Report to the U.S. National Highway Traffic Safety Administration (March 2005)
14. Gabler, H.C., Gabauer, D.J., and Bowen, D., “Evaluation of Cross Median Crashes, Final Report”, Report to the New Jersey Department of Transportation, FHWA-NJ-2005-004 (February 2005)
15. Gabler, H.C., Gabauer, D.J., Newell, H., and O’Neill, M., “Use of Event Data Recorder (EDR) Technology for Highway Crash Data Analysis, Final Report”, Report to the Transportation Research Board, National Academies of Science, NCHRP Project 17-24 (December 2004)
16. Gabler, H.C. and Hampton, C.E., “Event Data Recorders: Engineering Evaluation of Preliminary Field Data”, Report to the U.S. National Highway Traffic Safety Administration (December 2003)

17. Gabler, H.C., Bowen, D., and Molnar, C., "Modeling of Commuter Category Aircraft Seats, Final Report", Report to the Federal Aviation Administration Technical Center, FAA Research Grant 00-G-022 (March 2003)
18. Gabler, H.C. and Hampton, C.E., "Event Data Recorders: Engineering Evaluation of Initial Field Data", Report to the U.S. National Highway Traffic Safety Administration (December 2002)
19. Gabler, H.C. , "Development of a Low-Cost Automated Crash Notification System, Final Report", Report to the New Jersey Department of Transportation, FHWA-NJ-2001-027 (July 2001)
20. Hollowell, W.T., Gabler, H.C., Stucki, S.L. Summers, S., Hackney, J.R., "Updated Review of Potential Test Procedures for FMVSS No. 208", U.S. National Highway Traffic Safety Administration (1999)

INVITED PRESENTATIONS

1. Invited Presentation, "Risk of Injury and Fatality in U.S. Motorcycle Crashes with Traffic Barriers", University of Peradenyia, Kandy, Sri Lanka (April 2013)
2. Presentation, "Incidence and Risk of Concussive Injuries in Vehicle Crashes", 2013 Advanced Technologies and New Frontiers in Brain Injuries and Biomechanics Conference, Washington, DC (April 2013)
3. Invited Presentation, "Advanced EDRs Meet Advanced ACN: How Accurate are Advanced Automated Collision Notification Algorithms?", 2013 SAE Government / Industry Meeting, Washington, DC (January 2013)
4. Invited Presentation, "Field Performance of Rollover Curtain Deployment Sensors", 2013 SAE Government / Industry Meeting, Washington, DC (January 2013)
5. Invited Presentation, "Evaluation of Rollover Trip Conditions in Road Departures", TRB ANB 45 Committee on Occupant Protection (Rollover), Washington, DC (January 2013)
6. Presentation, "Feasibility of Restricted-use Licenses for Suspended New Jersey Drivers", 14th Annual NJDOT Research Showcase, West Windsor, NJ (October 2012)
7. Presentation, "The Effect of Barrier Design on Serious and Fatal Motorcycle Barrier Collisions", 14th Annual NJDOT Research Showcase, West Windsor, NJ (October 2012)
8. Presentation, "Injury Risk of Fixed Object Crashes", TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Irvine, CA (July 2012)
9. Presentation, "Fatality Risk of Motorcycle Crashes with Roadside Barriers", 2012 Military Biomechanics Conference, Washington, DC (April 2012)
10. Presentation, "Event Data Recorders in Crash Injury Research", Colorado State University, Fort Collins, CO (April 2012)
11. Presentation, "Evaluation of Rollover Trip Conditions in Road Departures", University of New South Wales, Sydney, Australia (February 2012)
12. Presentation, "The Characteristics of Rollover Crashes in Run-Off Road Events", SAE 2012 Government/Industry Meeting, Washington, DC (January 2012)
13. Presentation, "Event Data Recorders: Data Collection and Analysis in the U.S", Chalmers University, Goteborg, Sweden (October 2011)
14. Presentation, "Long-Term Roadside Crash Data Needs and Collection Strategies", AASHTO Technical Committee for Roadside Safety, Rapid City, SD (September 2011)
15. Keynote Lecture, "Light Vehicle Event Data Recorders – the Big Picture", 2011 SAE Event Data Recorder Symposium, Danville, VA (June 2011)
16. Presentation, "Preliminary Case Studies of Motorcycle-Barrier Crashes from NCHRP 22-26", TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Cleveland, OH (May 2011)
17. Presentation, "Advanced Automated Crash Notification for Improved Triage", 2011 Military Biomechanics Conference, Washington, DC (March 2011)
18. Presentation, "The Risk of Serious and Fatal Injury in Tree and Utility Pole Crashes: Early Findings from NCHRP 17-43", TRB Winter Meeting, AFB20 Roadside Safety Design Committee, Washington, DC (January 2011)
19. Presentation, "The Emerging Issue of Motorcycle-Barrier Crashes", Traffic Records Forum, New Orleans, LA (July 2010)

20. Invited Presentation, “Rollover Risk in Road Departure Crashes”, TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Napa, CA (May 2010)
21. Invited Presentation, SAE Expert Panel on Event Data Recorders, SAE World Congress (April 2010)
22. Invited Presentation, “Factors Related to Serious Injury and Fatal Motorcycle Crashes with Traffic Barriers”, TRB Summer Meeting, AFB20 Roadside Safety Design Committee, San Antonio, TX (June 2009)
23. Presentation, “Motorcycle Crashes: Fatality Risk, Guardrail Impact, and Training Effectiveness”, Symposium on Advanced Technologies and New Frontiers in Injury Biomechanics with Military and Aerospace Applications, Washington, DC (August 2009)
24. Organizer and Presenter, “Workshop on Criteria for Restoration of Longitudinal Barriers”, Sponsored by National Academy of Science, Presented to Iowa Department of Transportation, Mason City, IA (May 2009)
25. Presentation, “Reducing Motorcycle Fatal Crashes”, Virginia Department of Motor Vehicles (August 2008)
26. Invited Presentation, “Capturing Roadside Crash Data with Event Data Recorders”, TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Jackson Hole, WY (June 2008)
27. Invited Presentation, “Using Event Data Recorders to Evaluate Injury Criteria”, 2008 SAE Industry-Government Meeting, Washington, DC (May 2008)
28. Invited Presentation, “NCHRP Project 22-23: Criteria for Restoration of Longitudinal Barriers”, TRB Winter Meeting, AFB20 Roadside Safety Design Committee, Washington, DC (January 2008)
29. Invited Lecture, “Real World Crash Investigation”, 2007 AAAM Biomechanics of Crash Injury and Vehicle Crashworthiness Seminar, Melbourne, Australia (October 2007)
30. Invited Lecture, “Using EDR Data to Understand the Operation of Advanced Air Bags”, 2007 SAE Highway Vehicle Event Data Recorder Symposium, Washington, DC (September 2007)
31. Invited Presentation, “Fatality Risk of Motorcycle Crashes with Roadside Barriers”, TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Rapid City, SD (July 2007)
32. Invited Presentation, “Using EDR Data to Characterize Advanced Air Bag Performance”, 2007 SAE Industry-Government Meeting, Washington, DC (May 2007)
33. Presentation, “Introduction to the Use of Event Data Recorders for Crashworthiness Research”, 5th Annual Virginia Tech Center for Injury Biomechanics Symposium”, Blacksburg, VA (March 2007)
34. Invited Presentation, “Accuracy of WinSmash Delta-V Estimates: The Influence of Vehicle Type, Stiffness, and Impact Mode”, SAE Accident Reconstruction Symposium, Ventura, CA (November 2005)
35. Invited Presentation, “Accuracy of Event Data Recorders in High Severity Crash Tests”, SAE Accident Reconstruction Symposium, Ventura, CA (November 2005)
36. Invited Lecture, “The Risk of Injury in Far Side Crashes”, Wayne State University, Department of Biomedical Engineering (April 2005)

37. Gabler, H.C., Duma, S., and Stitzel, J., "Research Directions in the Center for Injury Biomechanics", 17th VT College of Veterinary Medicine Research Symposium (May 2005)
38. Gabler, H.C., "Aviation Safety Research in the Center for Injury Biomechanics", presented to BE Aerospace Corporation (March 2005)
39. Invited Lecture, "Harm and Injury Risk in Far Side Impact", Monash University Accident Research Centre, Melbourne Australia (February 2005)
40. Invited Presentation, "The Fatality and Injury Risk of Light Truck Impacts with Pedestrians", TRB Workshop on Pedestrian Safety, 84th TRB Annual Meeting, Washington, DC (January 2005)
41. Invited Lecture, "Introduction to Crash Compatibility", 2004 AAA Traffic Safety/Accident Investigation Conference, Bergen County Police Academy, New Jersey (October 2004)
42. Invited Presentation, "Event Data Recorders: the US Experience", IRCOBI seminar on "Accident Research – From Mass Data to Single Cases", Graz, Austria (September 2004)
43. Invited Presentation, Gabler, H.C., Gabauer, D.J., and Bowen, D., "Evaluation of Cross-Median Crashes in New Jersey", FHWA Median Barrier Safety Forum, Hershey, PA (September 8, 2004)
44. Gabler, H.C., Gabauer, D.J., and Bowen, D., "Evaluation of Cross-Median Crashes in New Jersey", Presented to the Commissioner of the New Jersey Department of Transportation and NJDOT Management (June 18, 2004)
45. Invited Presentation, "Feasibility of an Enhanced Emergency Locator Transmitter", presented to the National Transportation Safety Board (NTSB) at a meeting to identify advanced methods of locating airliners which crash at or near airports, Washington, DC (December 2, 2003)
46. Invited Presentation, European Passive Safety Network Committee on Roadside Safety, "Use of Event Data Recorders to Improve Roadside Crash Safety", Wolfsburg, Germany (October 2003)
47. Invited Lecture, 2003 Monash University Accident Research Centre Biomechanics of Injury and Vehicle Crashworthiness Short Course, Melbourne, Australia (July 2003)
48. Invited Lecture, Bergen County Prosecutor's Office, Fatal Accident Investigation Division, "Estimation of Crash Severity using Event Data Recorders" (September 2003)
49. Gabauer, D.J., and Gabler, H.C., "Validation of the Flail Space Model using EDR data" presentation at the Transportation Research Board A2A04 Roadside Safety Features Meeting, Minneapolis, MN (July 2003)
50. Gabler, H.C., "Use-Case Scenario for Roadside Safety Uses of EDR Data", presentation to the IEEE P1616 Motor Vehicle Event Data Recorders Standards Group, Washington, DC (May 2003)
51. Gabauer, D.J., and Gabler, H.C., "EDRs and Roadside Safety Needs", presentation to the IEEE P1616 Motor Vehicle Event Data Recorders Standards Group, Colorado Springs, CO (February 2003)
52. Gabler, H.C., "Event Data Recorders: Data Capacity issues", presentation to the IEEE P1616 Motor Vehicle Event Data Recorders Standards Group, Washington, DC (December 2002)
53. Presentation, New Jersey Department of Transportation "Development of an Enhanced Emergency Locator Transmitter" (November 2002)

54. Presentation, “Use of Event Data Recorders for Highway Crash Data Analysis”, presentation to the AASHTO Task Force on Roadside Safety, St. Louis, MO (September 2002)
55. Presentation, “Event Data Recorders: Link with Accident Databases”, presentation to the IEEE P1616 Motor Vehicle Event Data Recorders Standards Group, Washington, DC (September 2002)
56. Invited Presentation, New Jersey Department of Transportation “Development of a Low-Cost Automated Crash Notification System” (October 2001)
57. Invited Presentation, New Jersey Department of Transportation “The Feasibility of Automated Crash Notification” (October 2000)
58. Invited Presentation, Monash University/Holden Motor Corporation, Melbourne, Australia, “Side Impact Modeling Priorities: An Update" (July 2000)
59. Invited Presentation, Committee for a Smart New Jersey: Annual Symposium on Intelligent Transportation Systems, “Development of a Low Cost Automated Crash Notification System” (December 1999)
60. Invited Presentation, New Jersey Department of Transportation Research Showcase, “Automated Crash Notification” (November 1999)
61. Monash University, Melbourne, Australia, “Improved Side Impact Protection: A Search for Modeling Priorities" (July 1999)
62. Invited Speaker, SAE Small Car Safety TopTec, “The Demographics of Small Car Crash Safety”, (August 1998)
63. Invited Speaker, SAE Small Car Safety TopTec, “Car Crash Compatibility in the U.S. Fleet”, (August 1998)
64. Invited Speaker, European Experimental Vehicle Committee of the EU, “Systems Modeling of Crashworthiness”, (1998)
65. USCAR, Invited Presentation on “Crashworthiness Modeling for PNGV Vehicles” (1998)
66. SAE Industry / Government Meeting, “The Aggressivity of Light Trucks and Vans” (1998)
67. Monash University, Melbourne, Australia, “Global Optimization of Side Impact Crashworthiness” (1998).
68. SAE Government/Industry Meeting “Crashworthiness Systems Modeling and Optimization”, SAE Government/Industry Meeting (1997)
69. Honda Motor Company, “Vehicle Aggressivity and Compatibility”, (1997)
70. USCAR / Industry / Government, Invited Presentation on “Crashworthiness Modeling and Optimization” (1995)

SERVICE TO THE PROFESSION

☐ Associate Editor, *Traffic Injury Prevention* (2011-present)

☐ Board of Directors, Association for the Advancement of Automotive Medicine (2011-present)

☐ International Scientific Committee, Second International Symposium on Future Active Safety Technology (FAST-Zero), Nagoya, Japan (September 2013)

☐ Session Chair, "Roadside Safety Design: Vehicle-Roadside Interaction", TRB Summer Meeting, AFB20 Roadside Safety Design Committee, New Orleans (July 2013)

☐ Session Chair, "E-learning", Eighth International Conference on Computer Science & Education, Colombo, Sri Lanka (April 2013)

☐ Reviewer, NIH, Interdisciplinary Molecular Sciences and Training (IMST) Program Study Panel (2012)

☐ Session Chair, "Roadside Safety Design: Fixed Object Crashes", TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Irvine, CA (July 2012)

☐ National Academies of Science Advisory Panel for the NCHRP Project 17-58 on Safety Prediction Models for Six-Lane Urban and Suburban Arterials and One-Way Arterials (2011-present)

☐ Reviewer, Swedish Research Council, VINNOVA, the Swedish Governmental Agency for Innovations (2011)

☐ Session Chair, "Roadside Safety Design: Concrete Barriers, Bridge Rails, and Crash Test Criteria", 90th Annual Meeting of the Transportation Research Record (January 2011)

☐ Session Chair, "Research Needs for Roadside Safety Systems", TRB Summer Meeting, AFB20 Roadside Safety Design Committee, Napa, CA (May 2010)

☐ Transportation Research Board, Committee on Roadside Safety Design, AFB20 (2007-present)

☐ Reviewer, NIH, Interdisciplinary Molecular Sciences and Training (IMST) Program Study Panel (2010)

☐ Session Organizer, 2010 AAAM Student Research Symposium, 54th Annual Meeting of the Association for the Advancement of Automotive Medicine, Las Vegas, NV (October 2010)

☐ Conference Scientific Program Chair, 53rd Annual Meeting of the Association for the Advancement of Automotive Medicine, Baltimore, MD (October 2009)

☐ Chair, Scientific Program Committee, Association for the Advancement of Automotive Medicine (AAAM) (2008-2009)

☐ Vice-Chair, Scientific Program Committee, Association for the Advancement of Automotive Medicine (AAAM) (2007-2008)

☐ Scientific Program Committee, Association for the Advancement of Automotive Medicine (AAAM) (2005-2010)

☐ Session Chair, "Scientific Poster Presentations", 52nd Annual Meeting of the Association for the Advancement of Automotive Medicine, San Diego, CA (October 2008)

☐ Session Chair, "Young Drivers", 51st Annual Meeting of the Association for the Advancement of Automotive Medicine, Melbourne, Australia (October 2007)

- Session Chair, "Motorcycle Crash Compatibility with Roadside Barriers", TRB Summer Meeting, AFB20 Roadside Safety Committee, Rapid City, SD (July 2007)
- Session Chair, "Elderly Occupant Protection", 50th Annual Meeting of the Association for the Advancement of Automotive Medicine, Chicago, IL (October 2006)
- National Academies of Science Advisory Panel for the NCHRP Project 22-25 on Design, Layout, and Placement for Cable Barrier Systems (2007-present)
- National Academies of Science Advisory Panel for the NCHRP Project 22-14(03) on Roadside Safety Hardware Guidelines (2006-present)
- National Academies of Science Advisory Panel for the NCHRP Project 22-14(02) on Roadside Safety Hardware Guidelines (2002-2006)
- National Academies of Science Advisory Panel for the NCHRP Project 22-14(01) on Roadside Safety Hardware Guidelines (1998 – 2001)
- National Academies of Science Advisory Panel for NCHRP Project 22-15 on Vehicle-Infrastructure Crash Compatibility (1997 – 2004)
- National Academies of Science Advisory Panel for TRB Panel on Simultaneous Vehicle-Infrastructure Design (1997)
- Member, SAE Vehicle Event Data Interface (VEDI) Technical Standards Committee, Draft Standard J1698 (2003-present)
- Member, IEEE Motor Vehicle Event Data Recorders (MVEDRs) Technical Standards Working Group P1616 (2002-2004)
- Member, ASME Maritime Turbine Committee (2002-2004)
- Reviewer for *Journal of the American Medical Association*
- Reviewer for *Transportation Research Part C*
- Reviewer for *Journal of the Australasian College of Road Safety*
- Reviewer for the journal *Injury Prevention*
- Reviewer for the journal *Annals of Advances in Automotive Medicine*
- Reviewer for the journal *Transportation Research Record*
- Reviewer for the journal *Traffic Injury Prevention*
- Reviewer for the journal *Accident Analysis & Prevention*
- Reviewer for the *IEEE Transactions on Intelligent Transportation Systems*
- Reviewer for *International Journal of Crashworthiness*
- Reviewer for the *Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering*
- Reviewer for the *Journal of Intelligent Transportation Systems: Technology, Planning and Operations*
- Reviewer for *International Journal for Vehicle Systems Modeling and Testing*
- Reviewer, *IEEE International Conference on Computer Science & Education*
- Reviewer for the journal *Crash Prevention and Injury Control*
- Reviewer for *Journal of Engineering for Gas Turbines and Power*
- Reviewer for *Journal of Combustion Science and Technology*
- Reviewer for *Proceedings of the Combustion Institute*
- Reviewer for SAE World Congress, (2001, 2002, 2004, 2007-2013)

☐ Reviewer for the *Proceedings of the International Conference on Road Safety and Simulation* (2011, 2103)

☐ Reviewer for SAE Professional Development Program Technical Review Committee

☐ Reviewer, *Vehicle Compatibility*, v.1 and v.2, edited by Stanley H. Backaitis, SAE Book, PT-102 (2005)

☐ Session Organizer, 2003 SAE World Aviation Congress, Structural Analysis and Testing Session, Montreal, Quebec, Canada (September 2003)

☐ Session Organizer, 2002 SAE World Aviation Congress, Structural Analysis and Testing Session, Phoenix, AZ (November 2002)

☐ Session Co-Chair, 2002 SAE International Congress and Exposition, Crash Compatibility Session (March 2002)

☐ Session Chair, 1999 SAE International Congress and Exposition, Crash Compatibility Session (1999)

☐ Session Organizer and Chair, SAE Industry / Government Meeting, Crash Compatibility Session, Washington, DC (1998)

SERVICE TO THE UNIVERSITY

☐ Associate Department Head, Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2006-present)

☐ Member, Translational Biology, Medicine, and Health (TBMH) Graduate Program Committee (2012 – present)

☐ Search Committee for SBES Department Operations Manager for Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2012)

☐ Chair, Search Committee for Associate Department Head of Undergraduate Studies for the Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2010-2011)

☐ Member, Advisory Board for LISA (Laboratory for Interdisciplinary Statistical Analysis) (2011-present)

☐ Member, Search Committee for Associate Dean for Research and Graduate Studies for the Virginia Tech College of Engineering (2010-2011)

☐ Chair, Search Committee for Department Head of Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2008-2009)

☐ Virginia Tech College of Engineering Honorifics Committee (2009-present)

☐ Virginia Tech College of Engineering Graduate Program Committee (2005-present)

☐ Virginia Tech Initiative to Maximize Diversity (IMSD) Graduate Fellowship Evaluation Committee (2008-present)

☐ Chair, Honorifics Committee, Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2005-present)

☐ Chair, Graduate Program Committee, Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2005-present)

☐ Promotion and Tenure Committee, Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2005-present)

- SBES, Southern Association of Colleges and Schools (SACS) Accreditation Committee (2008-2010)
- Faculty Mentor, Virginia Tech College of Engineering Diversity Student Recruitment & Retention Grant (Summer 2008)
- Faculty Mentor and Instructor, Virginia Tech Bioengineering and Bioinformatics Summer Institute which seeks to recruit undergraduate engineering students from underrepresented groups (Summer 2008)
- Academic Council Member, American Institute for Medical and Biological Engineering, Representative for Virginia Tech-Wake Forest University, School of Biomedical Engineering and Sciences (2005-present)
- Virginia Tech, College of Engineering, Graduate Curriculum Committee (2005-present)
- Mechanical Engineering Faculty Search Committee (2006-2007)
- Mechanical Engineering Qualifying Examination Committee (2007)

GRADUATE THESES SUPERVISED

PhD Chair or Thesis Advisor

- Kristofer D. Kusano, " Methodology for Determining Crash and Injury Reduction from Emerging Crash Prevention Systems in the U.S.", PhD, Virginia Tech (2013)
- Allison L. Daniello, "Injury Mechanisms in Roadside Motorcycle Collisions", PhD, Virginia Tech (2013)
- Carolyn E. Hampton, "Injury Risk of Road Departure Crashes using Modeling and Reconstruction Techniques", PhD, Virginia Tech (2010)
- Craig P. Thor, "The Effectiveness of Graduated Driver Licensing in Reducing Crash Risk in the United States", PhD, Virginia Tech (2010)
- Douglas J. Gabauer, "Predicting Occupant Injury with Vehicle-Based Injury Criteria in Roadside Crashes", PhD, Virginia Tech (2008)

MS Chair or Thesis Advisor

- Thomas I. Gorman, "Prospects for the Collision-Free Car: The Effectiveness of Five Competing Forward Collision Avoidance Systems", MS, Virginia Tech (May 2013)
- Stephanie Kusano, "Feasibility of Restricted Driver Licenses for Suspended New Jersey Drivers", MS, Virginia Tech (July 2012)
- Nicholas Johnson, "Assessment of Crash Energy – Based Side Impact Reconstruction Accuracy", MS, Virginia Tech (May 2011)
- Kimberly Swanseen, "Effect of Belt Usage Reporting Errors on Injury Risk Estimates", MS, Virginia Tech (December 2009)
- Carolyn E. Hampton, "Limits of Permissible Damage in Strong-Post W-Beam Guardrail", MS, Virginia Tech (April 2009)
- Qian Wang, "Finite Element Modeling of Occupant Injury Risk and Crash Performance of W-Beam Guardrail Barriers in Roadside Crashes", MS, Virginia Tech (April 2009)
- Craig P. Thor, "Characteristics of Thoracic Organ Injuries in Frontal Crashes", MS, Virginia Tech (December 2008)

☐ Gregory Webster, “Feasibility of Transdermal Ethanol Sensing for the Detection of Intoxicated Drivers”, MS, Virginia Tech (June 2008)

☐ Christopher J. Molnar, “The Sensitivity of Aircraft Emergency Locator Transmitters to Non-Distress Impact Events”, MS, Rowan University (2005)

☐ Peter Niehoff, “The Accuracy of Energy-Based Crash Reconstruction Techniques using Event Data Recorder Measurements”, MS, Rowan University (2005)

☐ David W. Bowen, “Finite Element Modeling of a Commuter Category Aircraft Seat under Crash Loading”, MS, Rowan University (2003)

☐ Lewis T. Clayton, “Evaluation of Event Data Recorders in Real World Crashes

☐ and Full-Scale Crash Tests”, MS, Rowan University (2003)

☐ Douglas J. Gabauer, “A Methodology to Evaluate the Flail Space Model Using Event Data Recorder Technology”, MS, Rowan University (2003)

☐ Devon E. Lefler, “The Emerging Threat of Light Truck Impacts with Pedestrians”, MS, Rowan University (2001)

Committee Member, Thesis Reader, or Examiner

☐ Courtney Haynes Webster, PhD, Thesis – “Effects of Running Speed, Fatigue, and Bracing on Motor Control of Chronically Unstable Ankles” (2013)

☐ Myles D. Dunlap, PhD, Thesis – “Experimental Measurement of the Utricle's Dynamic Response and the Mechanoelectrical Characterization of a Micron-Sized DIB” (2013)

☐ Albert L. Kwansa, PhD, Thesis – “Molecular Dynamics and Mechanical Behavior of Collagen Type I and its Lysine/Hydroxylysine-derived Crosslinks” (2013)

☐ Kathryn L. Loftis, PhD, Thesis – “Development of Similarity Scoring Techniques for Motor Vehicle Crash Comparisons” (2013)

☐ Bradford Hendershot, PhD, Thesis – “Alterations and Asymmetries in Trunk Mechanics and Neuromuscular Control among Persons with Lower-Limb Amputation: Exploring Potential Pathways of Low Back Pain” (2012)

☐ Ray Daniel, MS, Biomedical Engineering, Thesis – “Head Acceleration Measurements in Helmet-Helmet Impacts and the Youth Population” (2012)

☐ Emily Miller, PhD, Biomedical Engineering, Thesis – “Exercise-Induced Low Back Pain and Neuromuscular Control of the Spine” (2012)

☐ Elizabeth de Rome, PhD, University of Sydney - Australia, Examiner, “Motorcycle Protective Clothing: Usage and Benefits” (2011)

☐ Sarbaz Othman, PhD, Chalmers University - Sweden, Opponent at defense of “Safety Evaluation of Road Characteristics: Addressing a Road, Vehicle and Driver System by Exploiting Diverse Data Sources” (2011)

☐ Steven Rowson, PhD, Biomedical Engineering, Thesis – “Head Acceleration Experienced by Man: Exposure, Tolerance, and Applications” (2011)

☐ Christina Seimetz, MS, Biomedical Engineering, Thesis – “Biomechanical Investigation of Head Kinematics and Skull Stiffness” (2011)

☐ Andrew Kemper, PhD, Biomedical Engineering, Thesis – “The Biomechanics of Thoracic Skeletal Response” (2010)

☐ Mao Yu, MS, Biomedical Engineering, Thesis – “Finite Element Analysis of Multiple Belt Restraint Configurations” (2010)

☐ Kathleen Bieryla, PhD, Mechanical Engineering, Thesis – “An Investigation of Perturbation-based Balance Training as a Fall Prevention Intervention for Older Adults” (2009)

☐ Kathryn Loftis, MS, Biomedical Engineering, Thesis – “Development of a Comparison Technique Between Crash Tests and Real-World Crashes” (2009)

☐ Joseph Cormier, PhD, Biomedical Engineering, Thesis – “Epidemiology and Biomechanical Analysis of Facial Fractures” (2008)

☐ Kerry Danelson, MS, Biomedical Engineering, Thesis – "Using Morphometric Analysis to Quantify Shape and Size Change in the Pediatric Skull" (2008)

☐ Emily Miller, MS, Biomedical Engineering, Thesis – “Effects of Obesity on Balance Recovery in Response to Small Postural Perturbations” (2008)

☐ F. Scott Gayzik, PhD, Biomedical Engineering, Thesis – “Development of a Finite Element Based Injury Metric for Pulmonary Contusion” (2008)

☐ Steven Rowson, MS, Biomedical Engineering, Thesis – “Impact Biomechanics of the Head and Neck in Football” (2008)

☐ Corrie Spoon, PhD, Biomedical Engineering, Thesis – “Hair Bundle Stiffness in the Turtle Utricle: Structural and Regional Variations” (2007)

CURRICULUM VITAE - MUKUL K. VERMA. PHD

Areas of Interest

- *Automobile Engineering, Analysis & Testing - Crashworthiness, Structures criteria, Handling properties*
- *Vehicle Safety :*
    - *Exterior Structure- Energy dissipation in crash, Door/Pillar/Roof in Side Impacts & Rollover;*
    - *Interior Components - Seat and Seatback structure, Occupant Impact with interior parts;*
    - *Windshield and Glass - Structural performance, Occupant Retention, Impact by Exterior objects;*
    - *Airbag Systems- Deployment & non-deployment criteria, Impact protection, Occupant retention;*
    - *Pedestrians' safety - vehicle structure relationship to impact severity.*
- *Active safety - Pre-crash sensors, Autonomous braking, Reversible restraints.*
- *Post-crash Safety - Vehicle factors in response and rescue time, Automatic Crash Notification system.*
- *Motorcycle Handling Dynamics*
- *Trucks & tractor-trailers rollover, Commercial & farm equipment – Boom truck safety.*
- *Tire Structures & Sensor systems, Effect on vehicle dynamics*
- *Mechatronics systems in automobiles - integrated mechanical, electrical and electronics system design*
- *Statistical analyses of traffic data.*
-

ACADEMIC CREDENTIALS

- ☐ **Ph.D.**, Mechanical Engineering & Applied Mechanics
- ☐ **M.S.,** Aerospace Engineering

PREVIOUS WORK EXPERIENCE

- Consultant, M. P. Holcomb Engineering Corporation (1/2009- 9/2012)
- General Motors: (8/1978 -11/2008)
    - Technical Fellow: Vehicle Safety & Structures, General Motors Product Development Organization (1999-2008);
    - Principal Engineer/ Systems Manager/ Staff Engineer, General Motors Engineering/ GM Research Laboratories, (1978-1999).
- Research Associate, Highway Safety Research Institute, University of Michigan (1975-78)
- Structural Engineer, Indian Space Research Organization (1973-74)

TEACHING EXPERIENCE

- Professor of Mechanical Engineering (adjunct), Lawrence Technological University, (2009- current)
- Graduate and Professional Development Courses- Department of Mechanical Engineering, University of Michigan (Dearborn), 1978-1985
- Vehicle Design for Safety - GMU classes at General Motors for Engineers & Executives

OTHER INDUSTRY EXPERIENCE

- Chairman, Experts' Workgroup for Enhanced Vehicle Compatibility *2003-2008*
- US industry representative – Traffic safety regulations
  - *OICA/ Group of Experts on Passive Safety (France) 2007-2008*
  - *VC COMPAT Final Workshop (Netherlands) 2006*
  - *International Harmonization Association (Germany*) 2005
- GM representative to USCAR 2007-2008
  - *Research projects in hydrogen fuel cell vehicle safety*
- Technical Sessions Organizer , Chairperson
  - *FISITA (International Federation of Automotive Engineering Societies)*
  - *SAE Annual Congress 1985 – current*
  -

PUBLICATIONS & PRESENTATIONS

TECHNICAL REPORTS & PUBLICATIONS ON WEB

1. *When Two Automobiles Collide* – Side Impacts & Vehicle Occupants' Safety; July 2012.
2. *Trends in Automobile Safety: Analysis of Recent NCAP Front Crash Tests*; January 2012.
3. *Summary of Keynote speech on Intelligent Tire Technology*, December 2011.
4. *Pedestrian Impacts with Automobiles*; April 2011.
5. *Airbag Deployment, Occupant Safety and Role of Vehicle Structure*; February 2010.
6. *Automobile Seat & Seatback Structure and Occupants' Safety in Crashes*; January 2010.

TECHNICAL PUBLICATIONS – INTERNATIONAL JOURNALS & CONFERENCES

1. *Invited Lecture **- scheduled***, "Sustainable Transportation and Requirements from Tire Technologies",
2. Tire Technology Conference and Expo, Cologne, Germany**,** February 2013.
3. *Invited Lecture **- scheduled***, "Tire Structure & Design Improvements for Meeting Future Requirements", Tire Technology Design & Development Summit, Detroit, December 2003,
4. Verma, M**.**, Vantsevich, V., Keynote Speech "Intelligent Tires – Past, Present and Future**"**, *4th Annual Conference on Intelligent Tire Technology, December 2011.*

5. Verma, M., Goertz, A., "Preliminary Evaluations of Pre-crash Safety System Effectiveness", Paper #2010-01-1042, *SAE Annual Congress, April 2010.*
6. Verma, M., "Evaluation of MDB as a Car Surrogate in LTV-to-Car Frontal Compatibility Tests": Part II GM Test Results", *SAE Government - Industry Meeting, Washington DC, 2008*.
7. Verma, M., Lange, R. and McGarry, D., "A Study of US Crash Statistics from Automatic Crash Notification Data", Paper 07-0058, *Enhanced Safety of Vehicles Conference, Lyon, France, 2007*.
8. Subramaniam, K., Verma, M., Nagappala, R., Tedesco, R and Carlin, L., "Evaluation of Stiffness Matching Concepts for Vehicle Safety Improvement", Paper 07-0112, *Enhanced Safety of Vehicles Conference, Lyon, France 2007.*
9. Verma, M., "Enhanced Vehicle Collision Compatibility - Progress Report of US Technical Workgroup for Front-to-Front Compatibility", Paper 07-0291, *Enhanced Safety of Vehicles Conference, Lyon, France 2007.*
10. Peddi, S., Subramaniam, K., Sharma, V., Verma, M., Schuyten, H., "Development of Mobile Deformable Barrier as a Car Surrogate", Paper 2007-01-1179, *SAE Transactions - Journal of Passenger Cars – Mechanical Systems, 2007*.
11. Verma, M., "Progress in Vehicle Collision Compatibility Improvements", Paper 09, *VC COMPAT Final Workshop, Eindhoven, Netherlands, 2006.*
12. Verma, M., Lavelle, J., Tan, S., and Lange, R.,"Injury Patterns and Effective Countermeasures for Vehicle Collision Compatibility", Paper 05-0173, *Enhanced Safety of Vehicles Conference, Washington DC, 2005.*
13. Verma, M., "Vehicle to Vehicle Crashes - Steps towards Increased Compatibility", *International Automotive Technical Conference, Dresden, Germany, 2005.*
14. Verma, M. Gupta, G., Sreekanth, M.,"Development of an MDB Concept for Crash Compatibility", Paper 2005-01-1374, *SAE Transactions, 2005, vol 114, p1645-1650.*
15. Verma, M., "EVC Technical Work Group Status; Chairman's Report", *SAE Government – Industry Meeting, 2005.*
16. Verma, M., Nagappala, R., Murugan, M., Tung, Y., "Evaluation of Structural Parameters for vehicle crash compatibility", *International Journal of Crashworthiness, vol. 9, no. 4, 2004.*
17. Verma, M., Nagappala, R., Tung, Y., Zimmerman, M., Murugan, M., Bernstein, M., "Significant Factors in Height of Force Measurements for Vehicle Collision Compatibility", Paper 2004-01-1165, *SAE Annual Congress, Detroit, 2004.*
18. Verma, M., Lavelle, J., Lange, R., "Perspectives on Vehicle Crash Compatibility and Relationship to Other Safety Parameters", Paper 412, *Enhanced Safety of Vehicles Conference, Nagoya, Japan, 2003.*

19. Verma, M., Lange, R, Lavelle, J., "Relationship of Crash Test Procedures to Vehicle Compatibility", Paper 2003-01-0900, *SAE Transactions, 2003, vol112, pp920-928.*
20. Chandra, J., Wawa, C., Verma, M., "Implementation and Validation of a Finite Element Approach to Simulate Occupant Crashes with Airbags: Part 1- Airbag Model", *American Society of Mechanical Engineers, Applied Mechanics Division, Vol. 169, 1993.*
21. Chandra, J., Wawa, C., Verma, M., "Implementation and Validation of a Finite Element Approach to Simulate Occupant Crashes with Airbags; Part II – Airbag Coupling with Crash Victims", *American Society of Mechanical Engineers, Applied Mechanics Division, Vol. 169, 1993*.
22. Verma, M., Repa, B., "Pedestrian Impact Simulation- A Preliminary Study", Paper 831601, *Stapp Car Crash Conference, San Diego, 1983.*
23. Verma, M., "Transient Response Test Procedures for Measuring Vehicle Directional Control", *Vehicle System Dynamics, 1981.*
24. Verma, M., Gillespie, T., "Roll Dynamics of Commercial Vehicles", *Vehicle System Dynamics, 1980.*
25. Verma, M., Scott, R., Segel, L., "Effect of Frame Compliance on the Lateral Dynamics of Motorcycles", *Vehicle System Dynamics, 1980.*
26. Gillespie, T., Verma, M., "Analysis of Rollover Dynamics of Double-bottom Tankers", Paper 781065, SAE Annual Congress, 1978.
27. Verma, M., "Theoretical and Experimental Investigations of Motorcycle Dynamics", PhD Thesis, University of Michigan, 1978.
28. Verma, M., Segel, L., Sayers, M., Winkler, C., Watanabe, Y., "A Study of the Free-Control Dynamics of Single-track Vehicles: The Adequacy of Linear Analysis", University of Michigan Research Report, 1977.
29. Verma, M., KrishnaMurthy, A., "Inelastic Post-buckling of Columns of Variable Flexural Rigidity", *Mechanics Based Designs of Structures & Machines, Vol. 3, 1974*
30. Verma, M., KrishnaMurty, A., "Nonlinear Vibrations of Non-uniform Beams with Concentrated Masses", *Journal of Sound & Vibration, Vol. 33, 1974.*
31. Verma, M., KrishnaMurty, A., "Nonlinear Bending of Beams of Variable Cross-section", International Journal of Mechanical Sciences, 1973.
32. Verma, M., KrishnaMurty, A., "Minimum Mass Design of Beams of Variable Cross-section", American Society of Mechanical Engineers, Journal of Applied Mechanics, 1973.

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