CrIS | Crash Imminent Safety UTC

Program Progress Performance Report

Project Title: Human Factors for Crash Imminent Safety in Intelligent Vehicles

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CENTER FOR AUTOMOTIVE RESEARCH

Overview:

The primary goal of the Crash Imminent Safety University Transportation Center (CrIS UTC) is **to increase understanding technology design and improve the ways humans interact with intelligent, automated and semi-automated vehicles, and to ultimately use this technology to save lives.**

The lead institution for this center is The Ohio State University (OSU) and consortium members consist of North Carolina A&T University (NCAT), Indiana University-Purdue University Indianapolis (IUOII), the University of Massachusetts Amherst (UMASS Amherst) and the University of Wisconsin (UW).

CrIS UTC is comprised of **seven interconnected research projects** that address four research strategies: driver interaction; pre-crash simulation; human physiology; and policy implications. **Each project has stand-alone research objectives described in detail in each project section of this PPPR**.

The Center produced its fourth newsletter at the beginning of March. On January 10-13, 2016, center researchers attended and made presentations at the 95th Annual Meeting of the Transportation Research Board (TRB) in Washington, D.C. Director Prof. Umit Ozguner attended the Council of University Transportation Center's meeting prior to the TRB meeting.

Collaboration is demonstrated through our institutional team partnerships and also through community and industry involvement at each of our institutions.

All project leads and collaborating institutions participate in a monthly CrIS UTC research leadership conference call to discuss our findings.

Weekly presentations on the projects are being conducted at North Carolina A&T State University to seek and share advice from other graduate students and faculty members.

The OSU team collaborates with state and local public partners, non-profit community partners and industry partners including Battelle, the City of Columbus, CISCO and the Mid-Ohio Regional Planning Commission (MORPC). At Ohio State, collaborations with DURA and Toyota Information Technologies continue.

Education and Outreach—F. Ozguner

Primary Goal: To transfer the knowledge gained through CrIS research efforts to the next generation of ITS engineers and for use to develop policies related to autonomous vehicle technologies through activities focused on technology transfer. In this past reporting period, CrIS UTC researchers undertook the following activities:

Activity 1-*STEM Summer Program:* We are making preparations to offer the highly successful Women in Engineering (WiE) RISE camp "How to Train Your Robot" for high-achieving high school students again in July 2016. Students will participate in a week-long workshop developed by graduate students and faculty at CrIS UTC where they will learn to program and use a mini robot named 'Sparki.' Sparki's abilities as a robot car mimic the same challenges of designing autonomous vehicles such as convoying, lane changing, line following, and object avoidance. The camp is offered in collaboration with the OSU College of Engineering.

Activity 2-*Undergraduate Honors Distinction Student:* An undergraduate student is designing and building a "Miniature Intelligent Vehicle Testbed." He is working on the image processing necessary to track tagged vehicles, the physical testbed itself, and the interface and control of the target miniature car robots.

Activity 3-*Senior Design Projects:* At NCAT, a team of undergraduate students are working on their senior design project by using the desktop driving simulator. They are gaining fundamental knowledge in research relating to crash imminent safety and driving simulators in general.

Activity 4-*Advanced Graduate Training:* ECE 5553 - Autonomy in Vehicles (Sp. 2016). Seniors and beginning graduate students are introduced to the concept of: autonomy in the context of modern vehicles; cruise control, anti-lock brake systems (ABS), steering control/lane keeping; introduction to automated highway systems (AHS).

Activity 5-*Graduate student exchange program*: Two Ph. D students from China are visiting Ohio State for a year: Kai Liu, a Ph.D. student from the Intelligent Vehicle Research Center, Beijing Institute of Technology (BIT), P. R. China; Yeqing Zhang, a Ph.D. student from the Key Laboratory of Intelligent Control and Decision of Complex System in Beijing Institute of Technology, China.

Additionally, planning is underway for OSU to host the summer graduate student exchange program for UTC students.

Facilities and Experiments—K. Redmill

- We have upgraded the operating systems and RTI driving simulation software to the most current version at both the OSU Driving Simulator Lab and the CITR simulation lab, which allows for model and software compatibility and facilitates the interfacing, performance, and operation of the networked simulation activities. UMass Amherst has installed Version 3.0 of the RTI software, added another RTI three screen simulator so that the UMass Amherst and OSU efforts to create distributed driving simulator experiments could proceed in parallel with the experiments which are running on the larger RTI simulator, and purchased and installed SimDriver in order to add a vehicle with some of the capabilities that we expect autonomous vehicles to have in the near future.
- We have also upgraded the furniture in the CITR simulator lab used by UTC researchers.
- As part of the Global Cities Initiative, we have fully automated two small vehicles- a golf cart and a single-person mobility scooter, in order to explore first and last mile transportation issues using small-scale people movers. This activity, partially supported by the UTC as well as an NSF Eager grant, is directly related to the UTC goals of vehicle and pedestrian safety and system reliability, and to increasing mobility by expanding access to transportation infrastructure. The city of Columbus is also a partner in this activity. This activity also requires an expansion of our wide-area communications equipment and capabilities.
- Undergraduate students, through the ECE capstone course, have designed, implemented, and revised the drive-by- wire functionality on these small vehicles.
- We continue to acquire access to naturalistic driving study databases for use by UTC researchers.

This includes the required IRB and human subject protocols training for researchers and students.

- We are automating a passenger sedan for studies on sensing and control issues related to automated parking and automated navigation in parking lots and garages, which are often the source for low-speed vehicle impacts.
- We are evaluating newly acquired Velodyne LIDAR sensors.
- We are studying the implementation of autonomous and semi-autonomous vehicles within the driving simulator software environment.
- There is continued development of the IUPUI/TASI automated braking performance testing environment and CAAIS, the computer assisted alcohol level feedback control device for use in driving simulator research.
- The UTC is working with other stakeholders to support the development of new automated and connected vehicle testing facilities at the Transportation Research Center in East Liberty. OH.

Project 1. Pre-crash Multi-vehicle Experimental Analysis Using a Networked Multiple Driving Simulator Facility
Investigators—Weisenberger (OSU), lead; Chen (IUPUI); Fisher (UMass); Homaifar (NCA&T)**;** Lee (UW); Ü. Özgüner (OSU); Redmill (OSU); Stredney (OSU)

Major Goals - Year 3: Design collaborative multi-vehicle experiments, and use the networked simulation environment to test hypotheses and collect/analyze data for multi-vehicle scenarios.

Accomplishments: Project 1 continues to work toward the networking of driving simulators across the institutions in the CrIS UTC.

Progress: We have made considerable progress toward this goal, both technically (getting simulators at different sites to talk with one another) and substantively (storyboarding scenarios that are ones involving multiple vehicles – and therefore multiple drivers). One of the biggest challenges in recent months was getting simulators at the partner universities on the internet so that networking could occur. Because the RTI software used by most of the partners was running on Windows XP platforms, partner universities were reluctant to allow these computers to be placed on the network, given Microsoft's discontinuation of support for this operating system. Further complicating matters was an upgrade in RTI's software. Version 3.0 of SimCreator and SimObserver is designed to run under Windows 7. Networking simulations that ran under the older versions of these programs did not immediately work under Version 3.0. Still further complicating the picture was the fact that RTI upgraded its version of SimDriver (the automated vehicle package) to Version 2.0. This would only run under Version 3.2 of SimCreator. Thus, another upgrade had to occur at both OSU and UMass Amherst.

Over the past few months, most of the partner universities, along with Ohio State, have upgraded both the operating system and the software for their simulators to Version 3.2. We have re-established a two-simulator joint scenario, where both vehicles can see each other as well as the traffic operating in the scenario. In the last few weeks, we have re-established the VPN connection with IUPUI and with UMass Amherst, and will proceed with getting joint simulation scenarios operative.

Plans: We hope to have the multi-simulator testbed in place at OSU and UMass Amherst in the next month. We have already designed the scenarios for the multi-simulator experiment and are now developing those scenarios. Drivers are estimated to be the cause of 95% of the crashes during the last few seconds over which a crash unfolds. We are hoping to understand why this is the case and, with that end in mind, design and evaluate a training program that can reduce the incidence and severity of multiple vehicle crashes. We expect to begin running an experiment as early as June of this year and we hope to submit a paper to TRB in August.

In addition, multi-simulator experiments are being developed for follow-up studies in our series on aggressive driving (see initial results description below). Specifically, we will use a multi-simulator approach to determining whether individuals drive more aggressively when there is another human actor in the scenario.

Goals and objectives: There has been no change in overall goals or objectives.

Products: A workshop on connected and distributed driving simulators was organized and co-lead by Don Fisher (UMass Amherst) at the Annual Meetings of the Transportation Research Board in January of 2016. Over 20 participants discussed the broad research agenda for connected and distributed driving simulators. Participants from the federal government, private industry and academics appeared as panelists and discussants. A report describing the activities of the workshop has been completed.

Additionally, Don Fisher served as a moderator of a workshop at the Annual Road Safety and Simulation Conference in Orlando, FL during November. The workshop was organized by the Office of Safety at the Federal Highway Administration (FHWA). Use cases for connected and distributed simulators at the FHWA were discussed

Collaborations: All of the partner universities in the CrIS UTC are part of this project. Primary work on the networking issues has been done by Thomas Kerwin (Research Scientist), Nishan Noronha and Patrick Veith (undergraduate students) at OSU and Siby Samuel and UMass Amherst. Several additional projects are underway in the OSU Driving Simulation Laboratory that are related to the overall goals of the UTC. These projects include:

1. A collaborative research effort with an industry partner to develop a comprehensive approach to develop "suites" of warning indicators for drivers in the vehicle. At present, notifications and warnings are developed by different teams of engineers creating different parts of vehicles, without much consideration as to how these warnings are perceived relative to each other, in terms of urgency or annoyance. The outcome will be guidelines for how to create effective systems of warnings and notifications for the driver. These guidelines will be important for keeping the driver informed as vehicles incorporate an increasing number of autonomous systems. We have completed studies involving warnings with visual and auditory components; the next experiments will introduce haptic stimuli into the warning set. Students participating in the project include Patrick Veith, Tyler Whitlock, Kevin Smearsoll, Sarah Kasper, and Sean Harrington (all undergraduates).

2. An effort currently underway with OSU faculty to assess the question of "road rage" among drivers, specifically the factors that increase aggressive behaviors in driving. Tyler Whitlock (undergraduate) has just completed the first experiment in this project as his senior research thesis in psychology. His results indicated that the presence of weapon-related cues in the driving environment led to an increase in driver aggression, specifically in vehicle speed and tailgating behaviors. Further, individuals who scored highly on a questionnaire aimed at trait narcissism similarly showed higher levels of driver aggression in vehicle speed and tailgating. Additional experiments are planned.

3. An assessment of how cognitive workload, the detectability and perception of warnings, and driver behavior are affected by the presence of other factors in the vehicle that are not currently classified as distractors by the NHTSA guidelines. In the first study, the impact of the presence and level of background music in the vehicle on situational awareness, driving performance and rated urgency of warnings and notifications is underway. Students participating in this project include Katelyn Silveous, Tyler Whitlock, Kevin Smearsoll, and Sarah Kasper. A first experiment was completed last year as part of Katelyn Silveous's undergraduate research thesis in speech and hearing science. A second undergraduate research thesis has just been completed, conducted by Sarah Kasper from Speech and Hearing Science. Her results extended the project of Katelyn Silveous from last year, in which it was found the loud levels of background audio in the vehicle were correlated with higher driving speeds and decreased urgency ratings of auditory warnings. Kasper's data further indicated that loud levels of background audio decreased driver situation awareness and impaired complex decision-making.

Additionally, NCA&T has bi-weekly meetings with Ohio State University, in which we update each other on our recent developments, discuss the challenges in research and receive useful feedback on how to solve the issues and move forward. For this project, we have worked closely together in order to connect our simulator to the network with the other participating universities and the related issues.

Impact: No impact has as yet been demonstrated. Upon completion, the existence of a network of driving simulators will provide a testing resource that does not currently exist elsewhere in the country. This will be a significant output of the center, which will contribute to outcomes by improving our understanding of driver interactions in crash-imminent scenarios, and ultimately to a broader impact in increasing safety for drivers of cars with autonomous vehicle systems.

Changes or Problems: It continues to be challenging to network the simulators across all sites in the UTC. However, we are making real progress, having now gathered bandwidth and time delay metrics showing the synchronous multi-site simulator experiments are possible. We believe that we will be running a connected simulator experiment at OSU and UMass Amherst in the upcoming month.

Project 2. Driver Models for Both Human and Autonomous Vehicles with Different Sensing Technologies and Near-crash Activity

Investigators—Ü. Özgüner (OSU), lead; Fisher (UMass); Homaifar (NCA&T)**;** Lee (UW); Woods (OSU)

Major Goals - Year 3: Ohio State has developed the multi-agent models of the driver and the vehicle that can be used to inform the design principles for optimized autonomous vehicles. In the first half of Year 3, we are refining our model-building and estimation efforts, and continuing to investigate possible closed-loop impact through future active safety systems that make decisions based on the insight generated by human driver models.

Accomplishments: CrIS UTC researchers are studying different methods of capturing driver behavior in computational and functional models. These models are developed as a means of understanding and quantifying human driving behavior, to be used in Advanced Driver Assistance Systems (ADAS) or partial/full automation applications.

In one particular study (Liu, January 2016), the CrIS UTC team at OSU proposed a lane change behavior classification approach to detect dangerous cut-in behaviors on highways. First, a probabilistic lane change behavior classifier was proposed based on Hidden Markov Models (HMMs). Then, time series data of lane changing vehicles from both normal and dangerous driving data sets were analyzed and compared to extract decisive features that are more likely to appear in dangerous lane change processes. A feature detection module was proposed specifically considering decisive features correlated to dangerous lane change. Furthermore, the feature detection module was integrated into the HMM classifier to enhance classification ability. The proposed classifier was verified with a separate test data set, and shows satisfactory results in reducing false negative rate of misclassification. This study was presented at the 2016 TRB Annual Meeting.

Further work on using the results of a driver estimator in active safety was presented at the 9th UTC Spotlight Conference on Connected and Automated Vehicles (Liu, November 2015). A model predictive control approach was proposed for a vehicle convoy traveling on homogeneous highway. Specifically, the lane change behavior of a cut-in vehicle in front of the vehicle convoy was estimated and predicted for the predictive control of the leading vehicle in the convoy. In order to capture state differences of the preceding vehicle in different lane change manners, a cost function considering riding comfort and spacing safety was designed for the leading vehicle based on the free headway set ahead. The proposed cost function integrates trajectory differences of the cut-in vehicle, which makes the controller sensible to different lane change manners. The space keeping and velocity tracking performance of the controller were tested and compared with a conservative controller under different lane change behavior of the cut-in vehicle. Furthermore, the control effects on the spacing and velocity of the followers in the convoy were analyzed. The simulation results showed that the controller considering lane change behavior difference has smaller velocity and spacing fluctuations dealing with lane change disturbance. To better predict similar driver behavior, better estimation of vehicle speeds was also investigated (Jing, September 2015), focusing on sparse V2V communications, and a broader survey was conducted to develop a better understanding of connected and automated vehicle options for these critical lane change maneuvers (Bevly, 2016).

UMass Amherst has worked on the development of Partially Observable Markov Decision Processes (POMDPs) that can be used when to intervene with a warning if a driver is identified as distracted. Recently, it has led to a possible resolution of the long-running difference between the risk posed by cell phones to drivers as determined by driving simulators, rather than as determined by naturalistic studies. Thesis research has led to multiple publications.

Several models of driver behavior in different scenarios are developed by the team at NCA&T. These models are based on Support Vector Machines (SVM), Hidden Markov Models (HMM) and Takagi-Sugeno (TS) Fuzzy models, and they are able to estimate a driver’s intention at an intersection.

NCA&T team has continued their work on modeling driver behavior at an intersection. A two-step algorithm is proposed which is an extension of our previously developed TS fuzzy model. In this technique fuzzy models are developed for each maneuver at the intersection. First, stopping is detected by comparing the data with the other moving maneuvers. If stopping is eliminated, then the turning or going straight actions are estimated using the rest of the maneuver models.

Another direction of the study in driver modeling is using One-Class Support Vector Machine (OC-SVM) for detection of abnormality in lane change maneuvers, obtained from naturalistic driving data of SHRP2 and 100 car driving study. In order to detect at what stage of driving a crash risk actually occurs, different steps in a near-crash lane change maneuver is compared with those steps in a normal lane change.

The human driver models developed by Hidden Markov Models (HMMs) are also improved by using Genetic Algorithm. Currently, the sensitivity analysis of HMM is an important issue that is being studied thoroughly. Sensitivity analysis of hidden Markov models (HMMs) is usually done based on small perturbations in the parameter values and re-computation of the output probability of interest. Recent studies have shown that sensitivity analysis is basically establishing a functional relationship that describes how an output probability varies as the network's parameters of interest do. To derive this sensitivity functions, existing Bayesian network algorithms have been employed for HMMs until now. These algorithms are computationally inefficient as the length of the observation sequence and number of parameters increase. In this work a new simplified matrix based efficient algorithm for computing the sensitivity function is proposed. The algorithm is compared with a recently developed technique called Coefficient-Matrix-Fill procedure and has shown a significant computational improvement.

Products: A number of conference publications were prepared, submitted or appeared as part of the work done in Project 2 in the last six months:

Ramyar, S., Anzagira, A., Homaifar, A., & Kurt, A. (2016). Fuzzy Model for Estimation of Driver's Actions at Intersections. Transportation Research Board 95th Annual Meeting, Washington, DC. (Submitted)

Liu, P., Kurt, A., Redmill, K., Ozguner, U. (2016, January). Classification of Highway Lane Change Behavior to Detect Dangerous Cut-in Maneuvers. Accepted to appear in *Proceedings of TRB 2016 Annual Meeting*.

Liu, P., Kurt, A., Redmill, K., Ozguner, U. (2015, November). Predictive Control of a Vehicle Convoy Considering Lane Change Behavior of the Preceding Vehicle. Accepted to appear in *Proceedings of 9th UTC Conference on Connected and Autonomous Vehicles.*

Strayer, D.L. and Fisher, D. L. (2016). SPIDER: A Model of Driver Distraction and Situation Awareness. *Human Factors*, *58*, 5-12.

Fisher, D.L. (2015). Cognitive Distraction in the Wild: Next Steps – Addressing a not so Humdrum Conundrum (commentary). *Human Factors*, *57*, 1331-1333.

Bevly, D., Ozbilgin, G., Kurt, A., Redmill, K., Ozguner, U. et. al. (2016). Lane Change and Merge Maneuvers for Connected and Automated Vehicles: A Survey. Accepted to appear in Intelligent Transportation Systems, Transactions on, IEEE.

Ramyar, S., Sefidmazgi, M. G., Amsalu, S., Anzagira, A., Homaifar, A., Karimoddini, A., & Kurt, A. (2015, September). Modeling Driver Behavior at Intersections with Takagi-Sugeno Fuzzy Models. In Intelligent Transportation Systems (ITSC), 2015 IEEE 18th International Conference on (pp. 2378-2383). IEEE.

S. Amsalu, A. Homaifar, "Driver Behavior Modeling near Intersections Using Hidden Markov Model based on Genetic Algorithm," in IEEE Intelligent Vehicles Symposium, June 19 -22, 2016. (Submitted)

Ramyar, S., Anzagira, A., Homaifar, "Identification of Anomalies in Lane change Behavior Using One-Class SVM". IEEE Intelligent Vehicles Symposium 2016, Gothenberg, Sweden. (Submitted)

Ramyar, S., Anzagira, A., Homaifar, A., & Kurt, A. "Fuzzy Model for Estimation of Driver's Actions at Intersections". World Automation Congress 2016, Puerto Rico. (Submitted)

Collaborations: NCA&T and Ohio State continue to work together to develop a driver model at an intersection using Hidden Markov Model and Support Vector Machine from a driving data collected in Ohio State University. NCA&T has also received the naturalistic driving data that was collected in Columbus, Ohio from Ohio State University. NCA&T faculty and students also attended the CrIS annual meeting which was held in Ohio State University in September 2015. During the event several faculty and students from collaborating universities, such as NCA&T, OSU and IUPUI who were involved in a similar research field met and exchanged ideas.

Impact: Nothing to report.

Changes or Problems: Nothing to report.

Project 3. Cognitive Attention Models for Driver Engagement in Intelligent and Semi-autonomous Vehicles

Investigators—Lee (UW), lead; Fisher (UMass); Homaifar (NCA&T)**;** Woods (OSU)

Major Goals - Year 3: In this project we undertake multiple ***Sub-Projects,*** each concentrating on a different aspect of refining the model of driver-automation interaction and assess performance in response to critical pre-crash safety events.

3.1 The Role of Attention in Intelligent and Semi-Autonomous Vehicles.

In December of 2014, UMass Amherst added SimDriver Version 1.0, an RTI software product, to its suite of simulator software. They upgraded to SimDriver Version 2.0 in the fall of 2015. In addition, they are helping add to the functionality of SimDriver that will allow the partners in this UTC with an RTI simulator to provide the driver's vehicle with the autonomous and semi-autonomous capability needed to evaluate the transfer of control from the automated driving suite (ADS) to the human driver and conversely.

1. It was shown that there are disrupting effects of brief single in-vehicle glances on hazard anticipation when compared with drivers who glance continuously at the forward roadway. In particular, eye movement analyses showed that interrupted drivers often failed to continue scanning for a potential hazard when their forward view reappeared, especially when the potential threat could not be localized easily. (Borowsky et al., 2014, 2015). The effect has been replicated and extended (Borowsky et al., 2016). The development of in-vehicle systems that were able to detect latent threats could help reduce the risk of in-vehicle glances on hazard anticipation. In this regard, an experiment was run to determine whether V2I communications could warn drivers in general of upcoming latent hazards without distracting them at the same time (Anzagira et al., 2015, 2016).

The results from Anzagira et al. (2015, 2016) indicated that general warnings a latent hazard would appear did not significantly improve latent hazard anticipation. We believe that this could have been an artifact of the way in which the scenarios were constructed and plan to repeat the experiment with a modified set of scenarios.

2. It was shown that among younger drivers the minimum duration of a glance on the forward roadway required to anticipate hazards when glancing back and forth between the inside of the vehicle and the forward roadway can be as much as seven seconds, assuming that the in-vehicle task does not require the driver to continue processing in-vehicle information while glancing up at the forward roadway (Samuel & Fisher, 2015a, Samuel and Fisher, 2015d). Additional time was required if the driver was performing an in-vehicle task, which loaded the driver even when looking on the forward roadway (Samuel, Romoser, Knodler, and Fisher, 2015c).

The current driver-vehicle interfaces have been shown to lead to especially long decision response times, but the DRT (decision response time) task is only a proxy for crash risk. Hazard anticipation is much more closely linked to crash risk. Experiments are planned which will better link DRT measures to actual crash risks.

3. An analysis was undertaken of the duration of successive glances in a sequence of glances inside the vehicle, multiple glances being typical of many of the in-vehicle tasks planned for semi- autonomous vehicles. Several different types of in-vehicle tasks were used. The sequential analysis of drivers' glance durations showed that any more than 2 glances were particularly problematic for some tasks, whereas all glances in a sequence (typically 6-7 glances to complete an in-vehicle task) were problematic when glancing at a GPS (Yamani et al., 2015). The sequential analysis of in-vehicle glance data can be useful for researchers and practitioners and has implications for the development and evaluation of task and interface design. Given that maps produce especially long glances among all glances in a sequence and given that maps are likely to be part of any semi-autonomous vehicle, it seemed important to determine whether an alternative display of the information in a map might decrease the frequency of especially long glances. Surprisingly, it did not do so (Takahashi et al., 2015).

We are planning to undertake an experiment where alternative map displays are used to present information, hopefully in a way that reduces glance durations further.

4. A model – the AC/DC (automatic control/driver control) – was developed for the emergency transfer of control from the ADS to the driver. The model can be used to predict the actions (e.g., steer left, brake) of the driver given knowledge of the driver's driving ability, and a subjective evaluation of his or her driving ability and trust in automation (Samuel, Horrey and Fisher, 2015b).

Now that we have SimDriver (Version 2.0) installed, we have two experiments we plan to conduct that will refine the model of driver-automation interaction and assess performance in response to critical pre-crash safety events. In the first experiment, we will be evaluating what information might be given to the driver just before a potential crash that could alert the driver to the responses most likely to avert a crash. In the second experiment, we will be evaluating what mode (or modes) of alert regain the driver's attention most quickly.

5. An experiment was run to determine the minimum time needed in order for a driver to remain fully situationally aware when control was transferred from the ADS to the driver. Using a driving simulator and eye tracker, it was determined that at least 8 seconds of warning was needed (Samuel and Fisher, 2016a, 2016b). An additional experiment was run to determine whether the minimum time that middle-aged drivers require to detect a latent hazard after control has been transferred is less than that of younger drivers. It was predicted that would be the case if the test of hazard anticipation is really measuring situational awareness since, in general, experienced drivers are better at anticipating hazards than inexperienced drivers. This was found to be the case (Wright et al., 2016).

We need to determine just how much time is needed for the orderly transfer of control to older drivers. In addition, we have an experiment planned to determine how much additional time is required to transfer control when the roadway environment before control was transferred to the ADS differs from the environment after control is transferred back to the driver (say, from an urban environment to a winding, rural two lane highway).

3.2 The Smooth Transfer of Control Between the Responsible Human Driver and the Artificial Driving Suite (ADS)

This sub-project asks several questions about bumpless transfer of control in shared control between human driver and Artificial Driving Suite (ADS). How does the responsible human transfer authority to the ADS for it to handle the vehicle within a defined limit of authority or a safe operational envelope (SOE)? Then when the situation and context change — the ADS is reaching the end of the delegated operational envelope — how does the human take back authority resuming direct control or re-task the ADS within a new limit of authority?

The goal is to investigate the form of shared control in terms of how the human driver delegates authority to the ADS to function autonomously within a specified safe operational envelope (SOE). The ADS then needs to monitor when it is beginning to reach the limit of the SOE as the driving situation and context changes, and in the event of onboard failures. Other work in Project 3 looks at how fast people can re-engage when signaled in different way (see 3.1 above). In this new model for shared control the human driver and ADS interact through delegating, monitoring and changing a shared SOE.

To study shared control in terms of monitoring and modifying a SOE requires simulating driving transition situations that require transfers of control between the responsible human driver and ADS have been captured. The transition scenarios (a) begin with an initial delegation of authority from the human driver to the ADS that specifies a specific SOE for that driving context; then (b) there is a change in the traffic situation or an anomaly that brings the ADS closer to the limits of its delegated authority; finally (c) the human driver and the ADS coordinate a re-authorization of SOE to adjust to the altered conditions.

Human in the Loop Controller (NHTSA Level 3 Automation): At this level of automation, vehicle is able to take over all safety-critical functions under certain traffic or environmental conditions from the driver and monitor for changes in those conditions to requiring transition back to driver control. Sufficient transition time is essential and driver attention is paramount, as the driver is expected to be available for occasional control. Human in the loop controller must therefore determine when an intervention is needed based on information about system and environment and switch to driver, only when critical

In sub-project 3.2, NCA&T is reviewing human in the loop controller design for NHTSA level 3 automation. We are also working on incorporating autonomous driving and some level of control on the RTI Desktop Driving Simulator. Driver distraction mitigation will be factored into the controller design when we progress to that. Transition time between controller and driver will also be taken into consideration in controller operation.

Results to date: Three scenarios of this form have been designed and implemented using the OSU driving simulator. The scenarios have been adapted to work around the limitations of the simulator for representing autonomous vehicle activity. The scenarios represent (1) a change in traffic situation that gradually pushed the ADS near its limit of authorization, (2) an anomaly where the ADS plan does not match the actual driving environment, and (3) an anomaly where a failure within the ADS reduces its safe operational envelope (SOE) and triggers the need for the human driver to become aware of the new more limited SOE. Currently, the planned study is being piloted.

Claims about autonomous operation confound delegation of authority with ADS capability for self-driving in limited conditions. This study explicitly studies the dynamics of delegation of authority and especially re-authorization as new events and traffic change occur. This is a new concept for shared control. The new form of human-autonomy interaction is based on responsible human and autonomous system interacting around changing an envelope of safe operation and based on communications in terms of delegation of authority from responsible human to autonomous capabilities.

The new concept has led to new project funded by NSF on Bumpless Re-engagement for Shared Control in Layered Networks jointly with MIT. The collaboration with MIT has resulted in development of a new approach that combines new findings in Resilience Engineering with adaptive control techniques. An initial test of the concepts using a classic dynamical model showed the new approach both improved transfer of control to human following an anomaly and improved control performance compared to classical automated controller. These are preliminary results with a simple instantiation of the new concepts.

Student Involvement: An undergraduate research assistant is assisting with scenario design and test runs.

3.3 Near Real-time Computation and Utilization of Maximum Safe Operating Envelopes in Coordinated Synthetic Driving

This sub-project addresses how to assess the risk of autonomy. The approach is to develop a risk analysis method for the potential for loss of control depending on the engineering pedigree of the autonomous capability/vehicle and the consequences of loss of control. The goal is to enable near real time calculation and utilization of a maximum safe operational envelope (nrt-max-SOE) based on a combination of the risk analysis and real time data about environmental conditions and human/vehicular activity nearby. The proposed approach to computation and assessment supports shifts to new envelopes as conditions and capabilities indicate the current envelope risks saturation or when conditions present new opportunities. The approach has three main components: maximum safe operating envelope, risk analysis of autonomy, near real time computation.

Maximum safe operating envelope:

1. keep activities inside the dynamic envelope as information about changing conditions comes in (open up or restrict activities as events occur and conditions change);

2. make bumpless shifts of control/authority across operating envelopes as conditions change (reengage other roles to pick the desired or appropriate operating envelope and forms of control);

3. recognize when operations get near to or risks going outside the envelope and trigger reassessments and model revision;

4. provide graceful extensibility as risk of saturation increases near envelope boundaries.

New form of risk analysis: Some readjustments to traditional risk assessment allow it to consider and be explicit about potential for brittle automation and the potential for loss of control (robustness and resilience). As a result, the risk analysis becomes ready to be actionable in real time.

Near real time: The connectivity revolution is all around us bringing a variety of data to bear at a point of action or point of inquiry. As we shop and search, a variety of factors are considered in real time to target results to that activity (micro ads, search results, point of sale). We can do the same for other activities to specify the “maximum safe operating envelope” for that activity given the risk analysis conditioned by current data and the contextual information available.

As the envelope shrinks or expands with current information, the basis for supervision, re-authorization decisions, and transfer of control changes. Mechanisms for smooth transfer of control are needed to manage these shifts in envelope. Current work examines how to assess the brittleness of any autonomous capability across situations and how to use this information to establish, adjust, and manage the SOE.

Results to date: The basic form of the new method for assessing the risks associated with autonomy has been developed. The basic form for making the risk assessment actionable as a new form of automated safety management has been developed. The innovation is responsive to the widely recognized need for new forms of V&V for autonomous vehicles by NASA and by the National Research Council reports. Dr. Woods presented parts of this work during an invited talk at the Hastings Institute Workshop on Control and Responsible Innovation in the Development of Autonomous Machines, April 25-26, 2016. This work has led to the award of a new grant from NASA with the Georgia Institute of Technology on “Research and Technology Development to Enable Human-Autonomy Teams.” The new project is expected to begin in the summer of 2016.

Products:

***Refereed Journal Publications*:**

Yamani, Y., Horrey, W.J., Liang, Y. and Fisher, D.L. (2015). Sequential in-vehicle glance distributions: an alternative approach for analyzing glance data. *Human Factors*, *57*, 567–572.

Borowsky, A., Horrey, W.J., Lian, Y., Garabet, A., Simmons, L. and Fisher, D.L. (2015). The effects of momentary visual disruption on hazard anticipation and awareness in driving. *Traffic Injury Prevention*, *16*, 133-139.

Samuel, S., & Fisher, D. L. (2016b, in press). Minimum time to Situation Awareness in Scenarios involving Transfer of Control from the Automation. *Transportation Research Record*.

Samuel, S., & Fisher, D.L. (2015d) – Evaluation of the Minimum Forward Roadway Glance Duration - *Transportation Research Record, 2015.*

Refereed Conference Proceedings

Fariadian, A. B., Annaswamy, A. M. and Woods, D. D. (2016). A Resilient Shared Control Architecture. Proceedings of ISSST 2016, May. Doi information v4 (2016).

Anzagira, A., Ramyar, S., Yan, Xuyang, Agana, N., Homaifair, A., and Fisher, D. L. (January 2016). Effect of Visual and Auditory Warnings on Latent Hazard Anticipation while Engaged in a Mock Cellphone Task. Proceedings of the 95th Annual Meeting of Transportation Research Board. Washington, D.C., January.

Borowsky, A., Horrey, W.J, Liang, Y., Garabet, A., Simmons, L., and Fisher D.L. (2016, under review). The effects of brief visual interruption tasks on drivers' ability to resume their visual search for a pre-cued hazard. *Accident Analysis and Prevention*.

Takahashi, M., Yamani, Y., Dündar, C., and Fisher, D. L. (January 2015). Evaluating effectiveness of partitioning complex visual displays on glancing behavior inside of vehicle. *Proceedings of the Transportation Research Board 94th Annual Meeting 2015*, Washington, D.C.

Samuel, S., & Fisher, D. L. (2015a). Evaluation of the Minimum Forward Roadway Glance Duration Critical to Latent Hazard Detection. *Proceedings of the Transportation Research Board 94th Annual Meeting 2015* (No.15-1707), Washington, D.C.

Samuel, S., Horrey, W. and Fisher, D.L. (2015b). A Predictive Model of Driver Response in a Level 2/3 Autonomous Environment. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Los Angeles: Human Factors and Ergonomics Society.*

Samuel, S., Romoser, R.E., Knodler, M., and Fisher, D.L. (2015c). Evaluating spillover effects on forward roadway glance durations. *Presented at the meetings of the Road Safety and Simulation Conference*, Orlando, FL.

Anzagira, A., Ramyar, S., Yan, X., Agana, N., Homaifar, A., and Fisher, D.L. (2015). Effect of Visual and Auditory Warnings on Latent Hazard Anticipation while Engaged in a Mock Cellphone Task. Proceedings of the Road Safety and Simulation Conference, Orlando, FL.

Samuel, S. and Fisher, D. L. (January 2016a). Minimum time to Situation Awareness in Scenarios Involving Transfer of Control from the Automation. *Proceedings of the 95th Annual Meeting of Transportation Research Board*. Washington, D.C., January.

Gibson, M. C., Lee, J. D., Venkatraman, V., & Price, M. (in press). Situation awareness, scenarios, and secondary tasks: Measuring driver performance and safety margins with highly automated vehicles. *Society of Automotive Engineers*.

Venkatraman, V., Lee, J. D., Schwarz, C. W., & Gunarathne, P. (n.d.). Benefits estimation of collision warning systems: Development of crash risk scales using what-if modeling techniques. *Society of Automotive Engineers*.

Wright, T., Samuel, S., Borowsky, A., Zilberstein, S., & Fisher, D. L. (2016, Accepted). Experienced Drivers are quicker to achieve situation awareness than inexperienced drivers in situations of transfer of control within a Level 3 autonomous environment. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*.

Collaborations: NCA&T and UMass Amherst have worked together over the summer (a graduate student from NCA&T spent time in the Human Performance Laboratory at UMass Amherst) and throughout the fall on a research project involving the use of visual and auditory warnings as a method for increasing drivers' awareness of latent hazards. Specifically, the study sought to determine whether non-specific auditory or visual warnings to pay attention to the road would reduce the distracting effects of engaging in cognitive secondary tasks (such as cell phone conversations) on latent hazard anticipation performance. The warnings were issued soon before the location at which the latent hazard could materialize.

NCA&T has been in contact with the University of Wisconsin in addition to UMass Amherst. Simulator study on investigation of the effects of visual and auditory warning on latent hazard anticipation was presented at the Transportation Research Board 95th Annual Meeting in collaboration with Professor Donald Fisher of the Human Performance Laboratory of UMASS.

Impact: A new team of undergraduate students (team DOT) have succeeded the previous team in working on their senior design project with the desktop driving simulator. They are working on various modifications on the simulator, thereby gaining relevant knowledge in the use of the driving simulator for research related crash imminent safety.

Two teams of undergraduate students are working on their senior design projects. Each team is being guided by few PhD students. In this project, their goal was to incorporate autonomous mode of operation to the already existing manual mode on the desktop driving simulator. Switching between these two modes was to be accomplished using an Arduino Microcontroller.

The goal of the project is to develop algorithms and solutions that will allow the two robots to interact with each other and humans. The robots are now able to perform actions such as: time-greeting, motion detection, follow-the-leader, customized movements, and a host of other functionalities. Some of the challenges included: limited amount of memory on the robots, poor camera resolution, and limited number of concurrent programs that could be on the robots.

These projects have helped undergraduate students develop a great variety of skills in Computer Programming, Simulations, control, interface, signal processing, etc. In addition, they have also been exposed to transportation and autonomy related research, and will be better prepared for future research work in graduate school and industry. Furthermore, the DOT funded project has tremendously impacted the research projects of other graduate students in our Testing, Evaluation, and Control of Heterogeneous Large-Scale Systems of Autonomous Vehicles.

Changes or Problems: The main issue being faced in these projects is the lack of experimental data. NCA&T has been working to develop various scenarios, collect data from experiments and more importantly integrate equipment such as eye tracker in order to be able to develop experiments on driver distraction. Currently, we are almost done with the eye tracker integration. However, it would beneficial if we could have greater access to the data that other universities have obtained by conducting various experiments, to have a benchmark for comparison and evaluation of our experiments.

Project 4. Bioinjury Implications of Pre-crash Safety Modeling and Intervention

Investigators—Bolte (OSU), lead; Weisenberger (OSU)

Major Goals - Year 3: Use Bio-Injury data from given crash scenarios to suggest evasive action / driver position best suited to reduce injury.

Accomplishments:

Progress (Phase II): The main focus during this period of performance was to use a 2nd database, CIREN – (Crash Injury Research & Engineering Network), which focuses on the details of injuries of very specific crashes. While CIREN is not statistically significant, it follows the occupants from the crash to the hospital and includes accident experts' opinions on what each mechanism of injury was (i.e. steering wheel, intruding door, air bag, etc.).

We currently have access to the public database and are looking at the 3 defined scenarios to see if the injuries in CIREN match the findings from NASS-CDS.

It is important to note that for a case to be considered for CIREN, an occupant in the vehicle must have sustained at least a serious injury according to the Abbreviated Injury Scale (AIS).

The first step was to scan the CIREN database and pull cases that match the scenarios stated in Phase I. A thorough CIREN search revealed the following number of cases for each scenario:

a. Lead Vehicle Stopped –59 cases
b. Vehicle turning – 160 cases

c. Vehicle changes lane – 20 cases

Lead Vehicle Stopped and Vehicle Turning scenarios have been investigated for patterns of injury mechanisms. The third scenario (Vehicle changes lane) will be investigated if more cases become available in the future.

Lead Vehicle Stopped Scenario

To date 59 case studies involving Lead Vehicle Stopped have been analyzed. As stated earlier, according to the statistical analysis of NASS-CDS for these crashes, the most common serious injuries were to the spine and lower extremities. The CIREN database revealed that the most common serious injuries (AIS 3+) occurred to the thorax, followed by the abdomen, and lower extremities. It is interesting that CIREN documented more thoracic and abdomen and less spine injuries than the statistical NASS-CDS query.

In the CIREN database, of the AIS 3+ injuries to the these regions, thorax injuries accounted for 35% of the injuries, of which close to 40% of the thorax injuries are AIS 4-5. Abdominal injuries accounted for 13% of the serious injuries in the Lead Vehicle stopped scenario with 20 % of them being AIS 4-5. Even though a large portion of the AIS 3+ injuries were to the lower extremities, almost all of them were only AIS 3 in nature. Truck under ride impacts and secondary impacts caused most of these severe injuries to the thorax, abdomen, and lower extremities, which could account for the difference in findings between the NASS-CDS and CIREN searches. The interior vehicle component that caused the most thoracic injuries was the steering wheel (sometimes through the airbag), suggesting that secondary impacts are causing these injuries. In these cases, 63% of occupants were wearing a seatbelt, and the frontal airbag deployed in 92% of cases. Frontal airbag availability on the case vehicle was an inclusion criterion for this study.

Vehicle Turning Scenario

To date, 160 cases studies involving a vehicle turning in front of a 2nd vehicle have been analyzed. As stated earlier, according to the statistical analysis of NASS-CDS for these crashes, the most common serious injuries were stated to be to the thoracic region. The CIREN database revealed that the most common serious injuries occurred to the thorax, followed by the head, and abdominal regions. These results are more similar than what was documented in the lead vehicle stopped cases.

Of the AIS 3+ injuries to these regions, serious thoracic injuries account for 47% of the injuries, serious head injuries account for nearly 35% and serious abdominal injuries account for 18% of injuries. In these cases, 86% of occupants were wearing a seatbelt, but the side airbag deployed in only 26% of cases. Many of the vehicles included in the study did not have a side airbag available and/or the available airbag did not deploy.

The leading mechanism of injury for these regions was contact with the intruding door structure, followed by b-pillar contact, and contacting a vehicle component through airbags. It will be interesting to further look at cases with varying airbags and other safety features to see if the injury patterns are different. Most of the severe injuries are happening in secondary impacts. For autonomous vehicle programming, we suggest looking into ways to prevent secondary impacts and reduce overcorrection by the driver following initial impacts.

Training or professional development: We have introduced three students (Tim Gocha, Tanisha Kashikar, and Lauren Eichaker) to database mining and statistical analysis. This project has allowed us to expand our research center into the realm of data mining. Lauren Eichaker has taken AAAM's AIS certification course to better understand the rules of AIS coding. She will take the AIS certification exam in the fall. This is proving to be useful on other ongoing projects in the center as well.

***Dissemination of Results*:** The NASS-CDS results have been submitted to the *Annals of Biomedical Engineering.*

***Plans for next period*:** CIREN findings will be analyzed further, defined further (e.g. belted vs unbelted occupants), and reported. CIREN findings will be submitted for publication. We plan to develop new research questions pertaining to the use of injury mechanism analyses for the design of autonomous vehicle behaviors.

***Products*:**

Publications – Phase I findings from the NASS-CDS have been written and submitted to the *Annals of Biomedical Engineering*. Phase 2 findings from CIREN are in the process of being written and will be submitted *to IEEE – Transactions on Intelligent Vehicles* (a new section of IEEE that will begin publishing

in 2016).
Posters- The results, findings, and implications of Scenarios 1 and 2 were presented at the Industry and Research Symposium at Ohio State (February 5, 2016). The results, findings, and implications of Scenarios 1 and 2 were discussed at the UTC Safety Summit in Washington, DC (March 30, 2016).

Data: The research will result in crash and injury databases that will be useful to better understand injuries which occur during the 3 defined crash scenarios.

Collaborations: We have been collaborating with the National Highway Traffic Safety Administration for access to the full CIREN database, which includes radiology images and reports. We also have been discussing correct use of the database and also various injury coding programs that could be used to better define cost to society.

Impact: Discipline: (1) The techniques being developed for mining both databases will help further the role of epidemiology in analyzing autonomous vehicle crash scenarios. (2) These techniques will be published and could also be taught to future researchers in the Injury Biomechanics course (Anat 7892).

Society: Having a better knowledge of injuries that occur in common crash scenarios will lead to safer vehicles and thus reduce fatalities and injuries in future crashes.

Changes or Problems: Nothing to report.

Project 5. Pre-Crash Interactions between Pedestrians and Cyclists and Intelligent Vehicles
Investigators—Chen (IUPUI), lead; Fisher (UMass); Ü. Özgüner (OSU)

Major Goals - Year 3: Sharing Pedestrian/Bicyclist Autonomous Emergency Braking Information in V2V Environment

Accomplishments: TASI at IUPUI has been working on two parallel activities. A summary of these activities are given below:

Activity 1. Integrate the active safety sensing information in V2V network. Our idea is to link V2V and autonomous emergency braking (AEB) capabilities together, and let a pedestrian AEB system tell other vehicles of the presence of pedestrians. If vehicles can exchange the pedestrian sensing information in real-time, a vehicle can get potential pedestrian crash information before itself can sense the potential crash, and hence, have more lead time to respond to the potential crash, improving safety. Three students have been working on this problem. The pedestrian AEB model developed previously is used in V2V-AEB simulation for vehicles to detect pedestrians.

Activity 2. Detect signature events in the surrounding environment from a large video dataset. In this period, data analysis of driving safety has been explored based on the driving video database. We are continuing our work on detecting pedestrians from video, detecting dangerous vehicle speed and computing TTC from video, and developing methods to visualize road appearances in compact image profiles extracted from long video clips. The classification of night illumination based on distributed video records and the visualization of road appearances have been published in SAE International Conference and accepted by Nicograph International 2016, respectively. The TTC computation from video and pedestrian detection from video has been submitted to International Conferences. The plan for the remaining period is to report and summarize the research outcomes to publish them at conferences. The major effort will be put on data mining to sort meaningful and useful information from the large video database. In pedestrian detection based on walking motion, various methods have been developed and examined for locating the characteristic chain of walking patterns in the motion profiles. A new method based on spatial-temporal filtering of the walking trajectories is being investigated for pedestrian classification. In vehicle collision avoidance, we extend previous zero-flow detection in horizontal orientation to the flow divergence extraction in vertical zones. This yields a stable TTC computation possible to be done in real time.

Major findings or results:

Activity 1. Vehicle to Vehicle (V2V) communication systems enable vehicles to share information to make safety related decisions. However, the safety improvement of the current V2V systems only benefits V2V-enabled objects in the V2V network. The Autonomous Emergency Braking (AEB) can utilize onboard sensors to detect non-V2V enabled objects and make safety related actions. However, AEB only benefits individual vehicles and the objects being detected. To further improve pedestrian safety, we have proposed the idea to integrate the capabilities of V2V and AEB together (call it V2V-AEB), which allows the information of pedestrians detected by onboard sensors to be shared in the V2V network. So a V2V-AEB enabled vehicle uses not only its onboard sensors, but also the on-board sensors of other vehicles through V2V messages to detect potential collisions and make better informed safety decisions. In this study, comprehensive Matlab/Simulink based simulation tool was developed. The purpose of this tool is to provide a logical information processing structure for supporting the development and evaluation of various algorithms needed for the successful application of the V2V-AEB systems. By using this simulation tool, users can easily develop and verify their information processing or control algorithms of the V2V-AEB system.

The development of the combined V2V-AEB system posts many challenges. One significant challenge for this V2V-AEB system is that when a subject vehicle receives many pedestrian position information messages from different vehicles, the subject vehicle does not know if each pedestrian reported by one vehicle is the same as the pedestrian reported by other vehicles. Therefore, it is necessary for the receiving vehicle to find how many actual pedestrians are actually on the road to keep tracking. A new method was developed to associate the pedestrians detected by different vehicles accounting the inherent inaccuracy of the pedestrian sensing from all vehicles. The method determines the possible number of actual pedestrians by grouping the close by pedestrians reported by different vehicles together and considers them as one pedestrian.

Activity 2. We have constructed an online driving video database with video clips, motion profiles, and attributes of traffic and environments. It has functions of upload and download similar to Youtube. It can also search clips of interest by attributes, and displaying temporal motion trajectories of vehicle and surrounding for data mining and accident analysis.

Plans for next reporting period:

Activity 1. Using the V2V-AEB simulation tool to develop algorithms for data processing required for V2V-AEB operations, specific problems including evaluating the quality of information fusion from different vehicles, message reduction method to avoid communication jam, adding temporal information in sensory fusion, emergency braking based on V2V-AEB information.

Activity 2. A new database component will be established to organize, retrieve, and mine road appearances in driving video, which will help the development of road departure prevention systems. This is the first online video database for large scale driving data. It will impact the big data mining in driving videos for extracting various parameters, understanding factors of accidents, and developing and testing algorithms in vehicle sensing and control. For example, new algorithms for pedestrian detection, road side detection, bicyclist detection, and so on will be beneficial from these big data resources.

Products:

Publications, conference, papers, and presentations:

Tang, B. "Pedestrian Protection Using the Integration of V2V Communication and Pedestrian Automatic Emergency Braking System." Master's Thesis. Purdue University, Indianapolis, December 2015.

Samuel, S. & Fisher, D.L. (2015, November). *Minimum Time to Situation Awareness when transferring Control from the Automation to the Human in the presence of Pedestrian*s. 9th Spotlight Conference on Connected Vehicle Technology, Washington D.C. Poster Session.

Tang, B., Huang, Z., Chien, S. & Chen, Y. *Pedestrian Protection Using the Integration of V2V And the Pedestrian Automatic Emergency Braking System*. IEEE 2016 Intelligent Transportation Systems Conference (to be submitted).

Huang, Z., Chien, S., and Chen, Y. *Vehicle Sensor Based Pedestrian Position Identification in V2V Environment*. IEEE 2016 Intelligent Transportation Systems Conference (to be submitted).

Representing the UTC, Dr. O'Connor has begun a dialog with the President of RealTime Technologies, the manufacturer of the driving simulators employed in the UTC grant.

Collaborations: TASS International is providing the PreScan vehicle simulation software to IUPUI as in-kind support for the development of the simulation model and pedestrian V2V-AEB simulation.

Facilities: Faurecia Emission Control Technologies, USA, LLC is providing vehicle test track to IUPUI for pedestrian/bicyclist CIB data collection.

Impact:
On the development of the discipline(s): The integrated V2V-AEB sensing enables the transmission of the detected pedestrians and cyclists information to other vehicles that potentially make the other vehicle get information earlier hence taking action to avoid the pedestrian crashes. The cost for this improved safety for vehicles is low. The video database developed in this project opens a new area of extracting intrinsic and statistical information through transportation data mining.
On the base of knowledge, theory, or methods: The V2V-AEB architecture abstracts the necessary operations required for the taking the advantages of this system, defines the specific sub-problems to be solved. The simulation model generated based on this architecture enables the modeling and testing of the solutions of the sub-problems easily.
On the development of transportation workforce development:
Two PhD students, four master students, and one undergraduate student are involved in this project. More students in graduate and undergraduate multimedia classes are involved in data testing and initial algorithm exploration.
On technology transfer: The driving video database allows uploading video from external users, which serves as a platform of data collection and analysis.

Changes or problems: Nothing to report.

Project 6. Safety Policy Implications and Information Dissemination
Investigators—Schuelke-Leech (OSU), lead; Ü. Özgüner (OSU), Weisenberger (OSU); Woods (OSU)

Major Goals - Year 3: Develop and modify pre-crash scenarios and experiment plans to better align with hypotheses and outcome assessments that inform policy recommendations.

Accomplishments: Several important activities were undertaken in support of the grant goals and objectives.

1. Three datasets for the empirical policy research were processed so that analysis could begin. The datasets are: the U.S. Congress from 1981-2014; the U.S. Court Opinions from 2005-2015; and an engineers' dataset. Papers are now being written from the dataset, including looking at how autonomous vehicles and vehicle safety are discussed in Congress. In addition, we are moving into looking at the moral and ethical issues associated with autonomous vehicles.
2. A successful forum was held on April 18, 2016 called "Moral Algorithms." This all day forum brought together experts from a range of field to discuss the technical, legal, and policy issues of autonomous vehicles. The forum was videotaped and a link will be available shortly on the UTC website.
3. Betsy Barry, B.J. Yurkovich from the Center for Automotive Research (CAR), and I have been working on a paper on Sustainable Transportation to be submitted to Transportation Research, Part D. We have also been working on a grant proposal to follow up on the research linking policy, sustainability, and autonomous vehicles.

What was learned: The research showed that autonomous vehicles are a small topic of conversation (this is not surprising). What is surprising is that the conversation is dominated by drones or unmanned aerial systems (UAS), where much of this technology comes from. When layered with vehicle safety, the conversation virtually disappears. That is, policymakers are not connecting autonomous vehicles to car safety in a meaningful way. In addition, when the larger issue of sustainable mobility was investigated, we found that there is virtually no connection between the conversations of sustainability (which focus mostly on wildlife and land management) and transportation/mobility. It appears at this point that regulatory and legal changes will be reactive, rather than proactive, engaging with the disruptive technology development early enough to smooth or guide the adoption of the technology. These findings will guide our engagement with policymakers, as we try to ensure that the policy and socio-technical issues that arise from the development and deployment of autonomous vehicles and smart technologies are acknowledged and understood. This is one of the reasons that we focused on the Moral Algorithms forum this spring.

Opportunities for Training and Professional Development: The video of the Moral Algorithms forum will be available for general viewing and training.

Dissemination of Results*:* Several presentation of the results were given this year, including: A presentation at the University of Minnesota in 2015 presenting the findings about autonomous vehicles and safety; a lecture on April 22, 2015 on sustainable mobility incorporating these results; Industry Studies Association May 2015 and May 2016. Several research papers are being revised and resubmitted for publication.

Next reporting period: In the next reporting period, we are planning to have four papers submitted and under review. We are also planning on hosting the fall forum.

Products: Nothing to report.

Collaborations: There are three collaborators working on this project: Dr. Betsy Barry, Dr. Clayton Darwin, and Suzanne Smith, JD. These three collaborators were visiting scholars at the CAR at OSU for a total of 10 months. Don Hubin and B.J. Yurkovich from OSU have also been working on supporting this project. Don helped to organize the Moral Algorithms forum.

Impact: This research supports work to engage policymakers and practitioners in a meaningful way. Empirical research is absolutely critical for data-driven policy.

This research is both methodological and substantively innovative to this field.

I have started to engage with people beyond the academic world to discuss the impacts of autonomous vehicles and car safety. I presented to a local community group in Ohio. I am looking to find other opportunities to do this kind of outreach.

Changes or Problem: Nothing to report.

Project 7. Technology and Enhancements to Improve Pre-Crash Safety

Investigators— Ü. Özgüner (OSU), lead; Chen (IUPUI); Coifman (OSU) Homaifar (NCA&T); Ekici (OSU); F. Özgüner (OSU); Redmill (OSU); Zheng (IUPUI); Koksal (OSU)

Major Goals – Year 3: In this project we undertake multiple ***Sub-Projects,*** each concentrating on a different new technology that may have an effect in improving pre-crash safety.

7.1 Secure Data Transfer Methods to Support Crash-Imminent Safety Situations

Accomplishments: Our effort has been to investigate secure, private, and efficient communication to support Crash-Imminent Safety systems. To augment the security of sensitive applications, our first research track concerns itself with enhancing the confidentiality of the communicated messages. In comparison with the adopted DSRC's low-level encryption primitives, we investigate the suitability of using a state-of-the-art low-level partial homomorphic encryption scheme to generate encrypted identities and keys to secure the transfer of sensitive data.

Our scheme [1] would neither need the key distribution and management of the symmetric encryptions, where if one key is captured the whole system is compromised, nor overlook the handshaking's privacy of the involved parties in the hybrid encryption where a preliminary step of openly exchanging the public keys is needed. Our second research track concerns itself with preserving location privacy of vehicles. To overcome the major deficiency of the basic framework and its inability to avoid tracking, changing pseudonyms is used to prevent eavesdroppers from easily linking the used single pseudonym with the vehicle's identity. Yet, the change must occur while the vehicle is either within an encrypted or silent-period hiding mix zone. To avoid the covering-encryption overhead and the silent-periods' lack of communication, we propose [2] the idea that the vehicle creates a dynamic mix zone using an alternative super anonymous authentication scheme to hide its pseudonym change. Once the change takes place, the originating vehicle watches for at least one other alteration by any cooperative neighbor in the formed zone before the vehicle automatically demolishes the group by reverting back to the baseline authentication. Finally, our third track of research falls within the augmentation of medium access layer to fulfill the efficiency of communication when collisions arise for safety beacons. The inabilities of beacons acknowledgments and delivery failures detection would increase the probability of beacon collision. Besides, many vehicles will compete for the single control channel based on the access mode adopted by the DSRC. In this regard [3], we try to mix the concept of grouping under lighten authentication, that we proposed in track 2, with the adjustment of beaconing rate to lower the vehicles' competition for the channel. Rather than having many individual vehicles communicate their information to the infrastructure, we can assign a high priority to the beacons of group leaders to let them communicate their whole group's information to the infrastructure.

Products:
Publications:

Al-Shareeda, S., and Ozguner, F., "Secure Pairwise Key Establishment in Vehicular Networks." In Proceedings of The 3rd IEEE International Conference on Connected Vehicles and Expo (ICCVE 2014), 105-111, Vienna, Austria, November 2014.

Al-Shareeda, S., and Ozguner, F., "Preserving Location Privacy Using An Anonymous Authentication Dynamic Mixing Crowd." To be submitted to The IEEE 19th Intelligent Transportation Systems Conference (ITS'16), Rio de Janeiro, Brazil, November 1-4, 2016.

Feng, Y., Al-Shareeda, S., Koksal, C.E., and Ozguner, F., "How Would Grouping Affect The Efficiency of Vehicular Beaconing?" To be submitted to The 2016 IEEE Conference on Communications and Network Security (ICNS'16), Philadelphia, PA, USA, October 17-19, 2016.

Collaboration: Nothing to report.

Impact: Nothing to report.

Changes or Problems: Nothing to report.

7.2 Cognitive Radio Based Communication

Major goals – Year 3: The major goal of our effort is to evaluate the performance of the vehicular cognitive radio networks in the presence of other heterogeneous secondary networks, and their application to radar based communication systems.

Accomplishments: During this reporting period, we explored the possibility of using automotive radar systems for communication purposes. The specific objective of our study was to identify if the collaborative use of automotive radars would improve the detection performance so as to leave resources for other communication sessions. Our simulation studies have revealed the following:

1. The information theoretical investigation revealed that collaborative use of radars reduce active usage period of radars, and allows other communication sessions to coexist in the radar band.
2. The fraction of time allocated to communication is heavily dependent on the correlated nature of observation by sensing points on two vehicles.

Dissemination: At this point, a conference paper is being prepared that outline our findings pertaining to this and the pervious reporting periods.
Next reporting period: We will modify our existing simulation framework to operate with the radar communication channels to test preliminary scenarios and algorithms.

Products: Theoretical tools to assess the feasibility of the aforementioned system, internal report.

Impact: Development of the principle discipline: Despite all reasonable efforts, 802.11p and DSRC radios have been identified as failing to carry the ever-growing communication traffic demand. With our new study, we expand the notion of cognitive radio technologies to the radar band so that two functions, i.e., communication and radar detection, can coexist in the same band. The direct advantage of this approach is that the competition for bandwidth in this frequency band is very little. However, direct line-of-sight communication is necessary to sustain such a communication system. Our theoretical study reveals that it is possible for such a joint system to function efficiently.

Changes/Problems: Nothing to report.

7.3 EEG and Lane Change Intent

Changes or Problems: This preliminary investigation has concluded. A larger budget and extended effort would be needed for more meaningful results.

7.4 Analyzing and Mining Big Data of Driving Videos for Crash Avoidance

Changes or Problems: Nothing to report.

7.5 Safety Implications of Traffic Dynamics in Congested Freeway Traffic

Accomplishments: This research has focused on driver behavior in the presence of large speed differentials between lanes. Preliminary results have found that drivers' car-following behavior not only depends on the lead vehicle in their lane, but also the speed of the adjacent lane.

Products:

Ponnu, B., Coifman, B., "Speed-Spacing Dependency on Relative Speed from the Adjacent Lane: New Insights for Car Following Models," *Transportation Research Part B.* Vol 82, 2015, pp 74-90.

Ponnu, B., "Impacts of Adjacent Lane Vehicles on the Speed-Spacing Relationship and Implications for Car-following Models," presented at the TRB seminar on Doctoral Student Research in Transportation Operations and Traffic Control, TRB Annual Meeting, 2016.

Collaborations: Nothing to report.

Impact: The findings enumerated in the accomplishments section are important because most car-following models strictly depend on the leader in the same lane as the follower. So this work has found a previously unrecognized dependency. These findings should eventually lead to more robust microscopic traffic flow models, which in turn will improve the performance of all applications that depend on these models (from safety applications, to traffic control, to urban planning).

Changes or Problems: Nothing to report.

7.6. Smart Cities: The First-Mile Last-Mile Problem

An effort was undertaken to develop slow-moving platforms (single-person or 4-people vehicles) that would provide transportation for the mobility-impaired in a smart city. The effort has been initiated by the City of Columbus and later supported by an NSF Project (through its CPS: Smart Cities Program).

Products: Two vehicles were developed for a demonstration.

Collaboration: City of Columbus, NSF.

Impact: This project provides an opportunity to investigate Crash Imminent scenarios for slow moving platforms in dense pedestrian environments and related human factor issues. It also provides an opportunity to deal with the legal and administrative aspects of autonomous vehicle deployment, albeit in a traffic environment different than roadways.

7.7. Smart Cities: An Efficient and Secure Communication Framework for Vehicular Communication Networks

Major Goals – Year 3: The overarching objective of our project is to design a framework to improve the performance of V2V and V2I communication as well as reduce the overhead at the application layer, all without sacrificing the level of security and safety achieved by the current existing approaches.

Major Issues Addressed: IEEE 1609 is the set of standards that specify the wireless access in Vehicular Communication Networks. Both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) network access is based on variants of 802.11, which sets the rules for infrastructure-free single-hop network communication. Furthermore, communication security of Vehicular Communication Networks is based on Public-Key Infrastructure (PKI), centrally managed by Certification Authorities (CAs) in order to help provide security by enabling protocols for authentication, confidentiality, etc. In the context of vehicular communication networking, there are some important questions concerning the efficiency and scalability of the aforementioned approaches:

Variants of 802.11 (802.11p for vehicular networks) -while being appropriate for a limited area of coverage- are not designed to support mobility. Indeed, there is typically no handoff protocol to move from one access point to another. Further, multiple access (MAC) is designed based on contentions, and contention resolution via randomization, which is efficient for long-sessions and a relatively low number of users. The contention period incurs a large overhead in the case of short packets, and the network throughput drops drastically as the number of users exceed a certain threshold. However, the current security protocol for V2V and V2I communication calls for the frequent broadcast of beacons (i.e., short packets) from each vehicle. Also, there are many dense scenarios (e.g., congested intersections, busy highways) in which the number of vehicles per access point/receiver is relatively high (i.e., high number of users). On top of that, PKI-based security is also known the have a large overhead at the application layer to achieve security.

Accomplishments: To address these issues associated with security and efficiency, we developed a group formation framework for vehicles. In our strategy, Road Side Units (RSUs) do not play a role in group formation. Instead, groups are formed in a fully-distributed fashion, and can change dynamically in time. Each group has a leader, chosen carefully according to a specific protocol. Note that, each vehicle that is not a part of another group is considered as a group itself with the only member being the leader itself, by definition. The memberships and leaderships are decided and updated depending on the channel estimates and signal strengths between vehicles. In our framework, each vehicle exchanges its state only with the group leader and the state of the group is communicated to the RSUs, only by the leader of each group. There are a number of advantages of our approach:

1. While the state (including, velocity, position, lane, etc.) of most vehicles is highly dynamically varying with respect to a stationary observer (e.g., static infrastructure), it remains relatively static with respect to the other vehicles that are commuting nearby. Thus, a neighboring vehicle, knowing its own state, can predict the state of a nearby vehicle fairly accurately even with much less frequent updates. We use this observation to reduce the frequency of V2V updates, sent by each vehicle to its leader.

2. By dedicating the V2I communication to the group leaders only, we transform the short-sessioned, high user-population communication setting of the existing approaches into one with long-sessions with only a few active users (leaders). This increases the network throughput significantly in 802.11p.

3. As for security, for the intra-group communication, we developed a new mobile authentication method to achieve the same-level of security, while reducing the application-layer overhead substantially. In our framework, authentication is guaranteed once between each group member and the group leader, and it does not need to be renewed as long as the members remain connected to the leader.

Products:

Feng Y., "Enhancing Eciency of Beaconing in VANETs," *MS Thesis - ECE, OSU*.

Feng, Y., Al-Shareeda, S., Koksal, C.E., and Ozguner, F., "An Efficient and Secure Communication Framework for Vehicular Communication Networks," to be submitted to IEEE CNS 2016.