CrIS | Crash Imminent Safety UTC

Program Progress Performance Report

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

October 30, 2016

Submitted to:	US Department of Transportation (USDOT) Research and Innovative Technology Administration (RITA)
Program Director/PI:	Umit Ozguner UTC Center Director Professor Emeritus, Department of Electrical and Computer Engineering Transportation Research Center (TRC) Inc. Emeritus Chair on Intelligent Transportation Systems (ITS) Crash Imminent Safety (CrIS) University Transportation Center (UTC) The Ohio State University ozguner.1@osu.edu 614-292-5141
Submitting Official:	Umit Ozguner ozguner.1@osu.edu 614-292-5141
Submission Date:	10/30/2016
DUNS Number:	832127323, EIN Number: 31-6025986
Recipient Organization:	The Ohio State University
Recipient Grant Number:	DTRT13-G-UTC47
Project/Grant Period:	10/01/2013 – 09/30/2018
Reporting Period End Date:	9/30/2016
Report Term or Frequency:	Semi-Annual

Signature of Submitting Official:

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 (IUPUI), 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**.

Our Center's Annual Technical Workshop was held on September 22, 2016, followed by a meeting with the Advisory Board the next morning. During the Workshop, progress in each project was outlined by a representative of that activity. The Board Meeting also covered developments in education, outreach, and a review of the Budget.

The Center produced its fifth newsletter at the beginning of September and is preparing an Annual Report for distribution by the end of October.

Director Prof. Umit Ozguner was invited to give the UC Riverside: "Mel Weber Memorial Lecture" at their annual meeting, and with an invitation from the UTC Program office, gave a presentation on April 20 in the "Transportation Innovation Series".

Apart from numerous technical conferences Center researchers attended and made presentations at, Director Professor Umit Ozguner and two graduate students from two partner Universities attended the CMU based National UTC organized "Annual Safety Summit" in Washington DC.

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 findings.

Weekly presentations on the projects are being conducted at NCAT to seek and share advice from 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, Ford Research, 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 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 offered the highly successful Women in Engineering (WiE) RISE camp for high-achieving high school students again last summer. 36 female high school students participated in a week-long workshop developed and supervised by graduate students and faculty at CrIS UTC, where they learned to program and use a mini robot named 'Sparki'. This year's group learned how to use basic programming concepts in a block programming environment in order to design the software for an autonomous car-like robot. Intelligent vehicle concepts of navigation, sensor use, lane keeping, obstacle avoidance, lane change, and intersection handling were covered in the lab exercises, culminating in a final competition in which the robots autonomously traversed an obstacle course resembling a city driving scenario.

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:* OSU, *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), and steering control/lane keeping; and introduction to automated highway systems (AHS).

UMass Amherst, *MIE 657*: Human Factors ***(***Professor Shannon Roberts **–** 3 semester credits). This course teaches graduate students about the range of human factors issues (e.g., situation awareness, cognitive distraction, mental models, trust in automation) that are relevant to the design and safe operation of automated, connected, and intelligent vehicles, especially as they influence the use, misuse, and disuse of automation, along with the abuse by the automation of the driver.

Activity 5- *Graduate student exchange program*:

Three Ph. D students are visiting Ohio State for a year: Kai Liu, Ph.D. student from Intelligent Vehicle Research Center, Beijing Institute of Technology (BIT), P. R. China; Yeqing Zhang, Ph.D. student from the Key Laboratory of Intelligent Control and Decision of Complex System in Beijing Institute of Technology, China; Ozcan Dulger, Ph. D. student from Department of Computer Engineering, Middle East Technical University, Ankara, Turkey.

A group of CrIS UTC students visited our labs at OSU July 14-22, as part of the 2nd Annual CrIS summer camp. On July 15 and 16, students from OSU, NCAT, IUPUI and Texas Southern University had a chance to work at the OSU Driving Simulator Lab. The group worked on different automated and connected vehicle platforms, including the small-scale urban autonomy testbed SimVille, and full-scale vehicles equipped with drive-by-wire (DBW) and dedicated short-range communication (DSRC) hardware. The experiments included:

- Introductory exercises to familiarize the students with the Player/Stage simulation and vehicle/robot interfacing software, and a tutorial on simple network connection, code compilation, and execution in a Linux environment.
- Automated lateral (steering) control for road following based on GPS measurements, simulated and tested on small-scale mobile robots serving as surrogate vehicles.
- Communication-based convoying: vehicle-to-vehicle (V2V) communication and automated longitudinal (throttle/brake) control
- Communication-based traffic light scenarios: vehicle-to-infrastructure (V2I) communication and longitudinal control
- Sensor-based obstacle detection: Processing and acting on LIDAR data
- V2I and V2X intersection safety and efficiency experiments on a full-size vehicle with longitudinal automation: intersections controlled by stop signs and traffic lights.

Facilities and Experiments—K. Redmill

- UMass Amherst has now added further capabilities to our SimDriver software. We are now able to control the autonomous car to execute turns at intersections, stop at stop signs, slow down and pull over by the side of the road in emergency situations, smooth maneuvers, etc. This provides additional flexibility in studying multiple vehicle conflicts. These additions to the software capability were made entirely by graduate students. When we purchased SimDriver from RTI, we knew we would want to have access to the code—we arranged to have that access with appropriate protections of their intellectual property rights also put in place.

- NCAT is in the process of moving to a new laboratory. The newly constructed space is more than 5000 square feet, and includes offices for theoretical research and computer simulations, as well as a testbed renovated to fit the requirements of an autonomous systems laboratory. In addition, NCAT has another lab in the north campus with an area of over 2000 square feet. This facility includes several offices and outdoor facilities.
- As part of the Global Cities Initiative, we have fully automated three small vehicles- a golf cart, a single-person mobility scooter, and now a second one-passenger vehicle, 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.
- We are studying the implementation of autonomous and semi-autonomous vehicles within the driving simulator software environment.
- The UTC is working with other stakeholders to support the development of new automated and connected vehicle testing facilities at the Transportation Research Center (TRC) in East Liberty. OH.
- This UTC is preparing a three to four vehicle experiment to be run at TRC, involving cooperative planning and control for merge and weave maneuvers.

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. Additionally, we have now reconfigured the FTP compiler and the REXEC service at the UMA end to allow for file transfer permissions consistent with Level 2 bridging needs.

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 now have the multi-simulator testbed in place at OSU and UMass Amherst. We have already designed and developed the controlled simulator scenarios for the multi-simulator experiment. Specifically, we will first study T-bone conflicts, and rear-end and head-on collisions, including the causative factors and remedial strategies. A total of 24 subjects will be evaluated across the 2 sites. The data collection will be time synchronized to measure temporal effects on behavior, particularly behaviors occurring in the final seconds and milliseconds preceding a crash. 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. This effort will be completed by January.

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

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, NCAT 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. And by January 2017, we believe that we will be running a connected simulator experiment at OSU and UMass Amherst.

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: OSU 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 second 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. The team at NCAT is currently focused on using machine learning tools to improve the performance of Advanced Driver Assistance Systems (ADASs). The sensitivity of Hidden Markov driver models previously developed is studied to increase the accuracy of the developed models. Moreover, Support Vector Machine models are developed for normal and dangerous driving that help the controller plan safe maneuvers, as well as create a basic situational awareness of the surrounding vehicles.

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 ADASs or partial/full automation applications.

In one particular study (Liu2016), the CrIS UTC team at OSU investigated the stabilization problem of a convoy of vehicles, using control methods that benefit from the behavior modeling and estimation schemes developed earlier in Project 2. The researchers developed theoretical foundations of the problem, which involves the study of a class of spatially decoupled systems by applying distributed model predictive control (DMPC) with switched cost functions. The proposed DMPC scheme switches the optimization index on a switching surface generated by control invariant sets. By applying the index-switching strategy, stability of the closed-loop system is ensured by the feasibility of a series of constrained optimal control problems. The stability conditions established in this note does not require terminal equality constraints of the optimization problem, and preserves the quadratic program property that is desired in practical applications. It is also observed that the proposed DMPC scheme has benefits dealing with systems that need to take into account safety-related spatial constraints.

In order to enhance our understanding of scenarios and technologies that driver models are applicable to, a new round of literature survey was conducted and published. To date, the majority of the literature has focused on longitudinal control topics, e.g. Adaptive Cruise Control (ACC), Cooperative Adaptive Cruise Control (CACC), etc. To a lesser extent, there have been a variety of research articles specifically dealing with lateral control, e.g., maneuvers such as lane changes and merging. The conducted survey (Bevly2016) provides an overview of this particular area of vehicle automation. The key topics addressed are control systems, positioning systems, communication systems, simulation modeling, field tests, surroundings vehicles, and human factors. The survey presented the current state-of-the-art of platoon merging/lane change control algorithms, as well as supporting relative positioning technologies, communication standards, simulation tools for concept evaluation, and considerations of vehicle surroundings. For platoon lane change control vehicle modeling, controller architectures, and specific control algorithms are presented that will allow for the augmentation of CACC control algorithms to allow lane change and merging. Current sensor packages of CACC capable vehicles are discussed as well as new algorithms for DGPS, computer vision, and sensor fusion.

The ability to predict drivers' intentions leads to the development of ADASs that can assist drivers in complex situations. Developing precise models of driver behavior can considerably reduce the number and severity of accidents at intersections. In our previous work, driver models near intersections are developed using Hidden Markov Models (HMM) and their performance is improved by training the models using Genetic Algorithm (GA) combined with Baum-Welch Algorithm. HMM is usually trained using Baum-Welch which is easily trapped at local maxima. GA solves this problem by searching the entire solution space. Continuous observations from the vehicle—e.g., acceleration, velocity and yaw rate—are used to train the models and estimate the driver's intention at each step. To investigate the robustness of the proposed models, the sensitivity analysis of the HMM model for parameter variation can be applied. Therefore, the study has been extended for HMM sensitivity analysis, which is usually done by taking small perturbations in parameter values and re-computing the output probability of interest. In recent studies, the sensitivity analysis has been investigated using a functional relationship that describes how an output probability varies as the network's parameters of interest change. A new simplified matrix-based efficient algorithm for computing the sensitivity function is developed.

ADASs are required to detect latent hazards posed by surrounding vehicles and generate an appropriate response to enhance safety. Lane changes constitute potentially risky maneuvers, as drivers involved encounter latent hazards due to surrounding vehicles. A careful study of lane change behavior is therefore essential in identifying potential abnormalities that may lead to various hazards, during the process of a lane change. In our work, an anomaly detection technique is used to compare snapshots of normal and dangerous lane change maneuvers, to identify the abnormal instances. A one-class support vector machine is used and tested for novelty identification based on naturalistic driving study data. The results show that the technique is able to detect dangerous lane changes with high accuracy. In addition, results suggest that dangerous behavior could occur before, after or during a lane change maneuver.

In order for the vehicles to be fully autonomous, they must be able to interact with the surrounding environment and plan and perform the driving maneuvers, independent of the human driver. In our study, an automated lane change system is proposed, where the decision making and trajectory planning are achieved by a model predictive controller (MPC). In addition, a safety monitoring system is also proposed, which detects the abnormal or dangerous instances in the controller's predicted output and notifies the controller to adjust its output accordingly. This system can be used to ensure the safety of the vehicle in situations where a computational error happens or the MPC optimization results get too close to the boundaries.

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

Liu, P., & Ozguner, U. (2016). Distributed Model Predictive Control of Spatially Decoupled Systems Using Switched Cost Functions. arXiv preprint arXiv:1606.02224.

Bevly, D., Cao, X., Gordon, M., Ozbilgin, G., Kari, D., Nelson, B., Kurt, A., Redmill, K., Ozguner, U. et. al. (2016). Lane Change and Merge Maneuvers for Connected and Automated Vehicles: A Survey. IEEE Transactions on Intelligent Vehicles, 1(1), 105-120.

Ramyar, S., Homaifar, A., Anzagira, A., Karimoddini, A., Amsalu, S., & Kurt, A. (2016, July). Fuzzy modeling of drivers' actions at intersections. In World Automation Congress (WAC), 2016 (pp. 1-6). TSI Enterprise Inc (TSI Press).

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

S. Amsalu, A. Homaifar, "Driver Behavior Modeling near Intersections Using Hidden Markov Model based on Genetic Algorithm," 2016 IEEE International Conference on Intelligent Transportation Engineering (ICITE 2016), Aug. 20-22, 2016.

S. Amsalu, A. Homaifar, "Sensitivity Analysis of Hidden Markov Models using Simplified Matrix Formulation for Filtering Probabilities on Transition Parameter Variation," IEEE Transactions on Knowledge and Data Engineering, (submitted).

Ramyar, S., Homaifar, A.,"Fuzzy Modeling of Drivers Actions at Intersections", presented in North Carolina A&T State University College of Engineering poster competition 2016. (Honorable mention)

Amsalu, S., Homaifar, A.," Sensitivity Analysis of Hidden Markov Models", presented in North Carolina A&T State University College of Engineering poster competition 2016.

Collaborations: In July 2016, Ms. Saina Samyar, a current graduate student of NCAT, attended the UTC summer exchange program in Ohio State University, where she learned about automated and connected vehicles, and tested the techniques on the computer simulation software, small-scale robots and full-scale vehicles.
NCAT and OSU continue to work together to develop a driver model at an intersection using HMM and Support Vector Machine from driving data collected at OSU. NCAT faculty and students also attended the CrIS annual meeting which was held at OSU September, 2016.

Impact: HMM Sensitivity analysis: The sensitivity analysis of HMM helps identify the weaknesses of this technique, which leads to the development of more accurate and robust models for human drivers. Lane-change Controller: A controller combined with safety monitoring system helps the ADASs design an optimal maneuver considering both safety and efficiency.

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.

The following projects have occupied most of our attention over the past period of performance. They have focused on human factors issues central to automated vehicles. Specifically, the projects have focused on: (a) the transfer of control in automated vehicles with Level 3 automation, both during expected and unexpected conditions; (b) the minimum forward roadway glance duration required during the monitoring of automated vehicles with Level 2 automation in order for the driver to maintain situation awareness; and (c) the larger human factors issues centered on the different levels of automation.

1. **Effect of Age on Development of Situation Awareness During Expected Transfer of Control**. Previous researchers examining transfers of control from semi-autonomous to manual driving have found that younger drivers engaged in a secondary task while in automated mode need at least 8 seconds to achieve the same level of situation awareness as drivers always in control of

their vehicle (Samuel et al., 2016). It is likely that middle-age drivers, with their increased driving experience would require less time. To test this hypothesis, middle-age drivers participated in a driving simulator experiment where they were asked to either drive manually (control) or with a simulated autonomous system (experimental conditions). While in automated mode, drivers either received an alert 4s, 6s, 8s, or 12s prior to the presence of a latent hazard. The proportion of latent hazards anticipated was examined. The results were consistent with the hypothesis that middle-age drivers were better at anticipating hazards overall and were faster to achieve appropriate situation awareness associated with manual driving than younger drivers. (Wright, T. J., Samuel, S., Borowsky, A., Zilberstein, S., & Fisher, D. L., 2016).

2. Effect of Change in Environment on Development of Situation Awareness During Expected Transfer of Control. From previous experiments, we know that control must be transferred to the driver in a Level 3 vehicle at least 8s before the driver passes a latent hazard in order for the driver to be as aware of the latent hazard as the driver is when glancing continuously on the forward roadway. In these experiments, the driving environment remained consistent throughout the time the Automated Driving Suite (ADS) was engaged and immediately after control was transferred to the driver. Considering the fact that drivers expect different categories of hazards in different driving environments, a transition to a different environment while the ADS is engaged may impair a driver's ability to both achieve situation awareness and successfully mitigate hazards. The current experiment examined if 8s was a sufficient amount of time for drivers to achieve situation awareness and appropriately mitigate hazards when the roadway environment changes while the driver is engaged in a secondary activity which takes his or her eyes away from the forward roadway. Drivers' eye movements and vehicle metrics were recorded as they completed one of three conditions in a driving simulator: an automation condition where the driving environment remained consistent throughout; an automation condition that contained some transitions to a new environment while the driver engaged the ADS; and a manual driving condition that also contained the same transitions as the latter automation condition. The results suggest that even 8s is not enough time for drivers to achieve situation awareness and mitigate hazards when the hazards are unexpected. (Agrawal, R., Wright, T. J., Samuel, S., Zilberstein, S., & Fisher, D. L., 2017).

3. How Best to Make Drivers Situation Awarene During Unexpected Transfer of Control. Typically, drivers in a Level 3 automation environment need at least 8s following a manual take-over request to achieve appropriate levels of situation awareness. Studies that have derived this time estimate use general audio alerts that suggest a transfer of control from the automation to the driver might be required. The current experiment examined if improvements in younger drivers' situation awareness might be observed in as little as 4s prior to when a latent hazard might materialize and a transfer of control occurs if more specific audio alerts are used. Younger drivers were randomly assigned to 1 of 4 between-subjects cue conditions: 1) a general cue condition, 2) a condition that described the risky feature(s) of the roadway and the location of those features, 3) a condition that contained information regarding the actual identity of the threat and the required behavior, 4) a combination cue condition (both environment and threat cue). Eye-movements were recorded as drivers completed six scenarios in a simulated automated driving experiment. The results showed that audio cues that contained information regarding risky roadway features increased the detection of latent hazards by almost 40% compared to when a general cue or a threat cue was used. Performance with the combined cue was no better than performance with the environment cue. The environment cue gives drivers the critical seconds needed to mitigate a potential crash. Results are informative regarding which types of alerts to use to inform drivers of upcoming hazards. (Wright, T. J., Agrawal, R., Samuel, S., Wang, Y., Zilberstein, S., & Fisher, D. L., 2017).

4. Minimum Forward Roadway Glance Duration – Level 2 Automation. Performance of in-vehicle, secondary tasks while driving requires a driver to alternate his glances between the inside of the vehicle and the forward roadway. While previous research has determined the thresholds of off-road and on-road glances critical to latent hazard detection, there was no research conducted to predict the probability of hazard detection in a time series considering all forward roadway glance durations within an alternation sequence. To determine the minimum forward roadway glance duration for alternation sequences with varying forward roadway glances, 45 drivers were asked to navigate a virtual environment while alternating their glances inside (2s) and outside (1s, 2s, 3s, 4s) the vehicle across 8 scenarios. A micro-benchmark approach based on Hidden Markov Models is introduced to infer the transition probability of hazard detection changing dynamically between stages. The model is cross-validated, and demonstrated to be accurate and robust. Three different characteristics of total experiment time were tested in the model. Using the ground truth transition probability from fixed forward glance duration, the probability of hazard detection in variable forward glance duration within an alternation sequence was computed. Over variable time-windows, a different ordering of scenarios (permutations of sequences) showed that a short history (10s) of glance behavior is sufficient for hazard detection (greater than 50.0%). In a longer history, at least four alternations of 3 s of forward roadway glance duration are required for a sufficient detection. Appropriate countermeasures to increase a driver's forward glance duration can be introduced whenever the detection probability is predicted low. Park, H., Gao., S., & Samuel, S. (2017).

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, NCAT is reviewing human in the loop controller design for NHTSA level 3 automation. We are studying 100 car study driving data to identify common features in different near crash/ crash scenarios. There are external factors such as slow or fast surrounding vehicles, unexpected events such as dark roads, internal factors such as distracted or drowsy driver exist that contribute to pre-crash event. Such insight into data will be used to determine the switching point between manual and autonomous driving.

Results to date: Initial simulator tests have been run where the responsible human and ADS conduct shared control by modifying the shared SOE. The results have led to formulation of a new architecture

for shared control in human-autonomy systems, and a new project funded by NSF on Bumpless Re-engagement for Shared Control jointly with MIT. The latest work has used new ideas on resilient control to design a new kind of shared control system for Bumpless Re-engagement. The key to the approach for resilient shared control is regulating the parameter of Capacity for Maneuver (*CfM*) – the remaining range or capacity to continue to respond to ongoing and upcoming demands. Control then should seek to minimize the risk of exhausting a unit's capacity for maneuver as that agent responds to changing and increasing demands (risk of saturation). In the scenarios studied Capacity for Maneuver is lost when the ADS is reaching the end of the delegated operational envelope. The increasing risk of saturating *CfM* triggers re-engagement and re-authorization of a new SOE. The results indicate resilient shared control based on reducing the risk of saturating *CfM* allows a timely and effective human re-engagement following an anomaly.
Student Involvement: An undergraduate research assistant has helped develop and test the scenarios.

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 risks associated with deployments of autonomous capabilities and the development of new architectures for human-autonomy teaming that achieve the benefits while also addressing the new forms of risk. The risks are associated with the increasing complexity of the computational and sensing resources needed to deliver autonomous capabilities. As this complexity increases, new risks appear and grow — related to the brittleness of complex systems, risks that cannot be addressed with conventional approaches to levels of automation and to human-machine interfaces.
Results to date: The work has highlighted a number of new risks that grow as complexity increases. The work has developed a new model for risk-informed calculation of maximum safe operating envelopes for delegating authority to an Artificial Driving Suite (ADS). The goal is to specify a new architecture for human-autonomy teaming based on near real-time computation and utilization of maximum safe operating envelopes. A new project has been awarded by NASA that includes these ideas by on Human-Autonomy Teaming with Georgia Institute of Technology.

<u>Products:</u>

***Refereed Journal Publications*:**

Borowsky, A., Horrey, W.J, Liang, Y., Garabet, A., Simmons, L., and Fisher D.L. (2016). The effects of brief visual interruption tasks on drivers' ability to resume their visual search for a pre-cued hazard. *Accident Analysis and Prevention, 93*, 207-216.

Fisher, D.L., Lohrenz, M., Moore, D., Nadler, E., and Pollard, J. (2016). Humans and intelligent vehicles: The hope, the help and the harm. *IEEE Transactions on Intelligent Vehicles*, *1*, 56-67.

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

Woods, D. D. (2016). The Risks of Autonomy: Doyle's Catch. *Journal of Cognitive Engineering and Decision Making*, 10(2), 131-133.

Refereed Conference Proceedings

Wright, T. J., Samuel, S., Borowsky, A., Zilberstein, S., & Fisher, D. L. (2016, September). 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* (Vol. 60, No. 1, pp. 270-273). SAGE Publications.

Agrawal, R., Wright, T. J., Samuel, S., Zilberstein, S., & Fisher, D. L. (2017, Accepted). The effects of a change in environment on the minimum time to situation awareness in transfer of control

scenarios. In *Proceedings of the Transportation Research Board Annual Meeting*.

Wright, T. J., Agrawal, R., Samuel, S., Wang, Y., Zilberstein, S., & Fisher, D. L. (2017, Accepted). The effects of alert cue specificity on situation awareness in transfer of control in level 3 automation. In *Proceedings of the Transportation Research Board Annual Meeting*.

Park, H., Gao., S., & Samuel, S. (2017, Accepted). Modeling effects of forward roadway glance durations on latent hazard detection. In *Proceedings of the Transportation Research Board Annual Meeting*.

Anzagira, A., Homaifar, A.," Effect of Visual and Auditory Warnings on Latent Hazard Anticipation while Engaged in a Mock Cellphone Task.", presented in North Carolina A&T State University College of Engineering poster competition 2016.

Fariadian, A. B., Annaswamy, A. M. and Woods, D. D. (2016). Towards A Resilient Control Architecture: A Demonstration of Bumpless Re-Engagement Following an Anomaly. *Proceedings of the International Symposium on Sustainable Systems and Technologies* (ISSN 2329-9169). Jun-Ki Choi and Annick Anctil, co-editors, Sustainable Conoscente Network, ISSSTNetwork@gmail.com.

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).

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*.

Other Publications

Woods, D. D. (2016). Resilience as Graceful Extensibility to Overcome Brittleness. *Resource Guide on Resilience*. EPFL International Risk Governance Center. v29-07-2016 (IRGC), Lausanne, Switzerland. https://www.irgc.org/wp-content/uploads/2016/04/Woods-Resilience-as-Graceful-Extensibility-to-Overcome-Brittleness.pdf

Collaborations: UMass Amherst has been collaborating with researchers at the Liberty Mutual Research Institute for Safety (LMRIS) in Hopkinton, MA on several of the projects involving automation. They have an ongoing Postdoctoral Program with UMass Amherst, UMass Lowell and Harvard that provides broad exposure for our postdocs and graduate students. One doctoral student spent her summer at LMRIS.

Impact: The National Highway Traffic Safety Administration will soon be publishing driver-vehicle interface (DVI) guidelines that automobile manufacturers will look too in the future when they install new interfaces. Donald Fisher served as a reviewer for these guidelines. The guidelines are comprehensive and as important to automobile manufacturers that have no automated features as they are to automobile manufacturers who have fully automated features incorporated into the vehicle.
At NCAT, the results from analysis of the 100-car naturalistic dataset will help us have a better understanding of human behavior in near crash scenarios both in the ego vehicle as well as surrounding vehicles. This information can be integrated with controllers for safer semi-autonomous vehicles.

Changes or Problems: At UMass Amherst, there have been no major challenges, though there continue to be ongoing minor issues with the simulator. But those are to be expected. One graduate student has left NCAT due to personal reasons, we have now hired a new graduate student to take over his task.

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: Phase II was continued into the 3rd year, with a goal of looking at the 3rd scenario and re-analyzing the 1st two scenarios using newly applied statistics. Due to this re-analysis, a brief re-cap of all findings is below.

Progress (Phase II): The Crash Injury Research & Engineering Network (CIREN), a database that focuses on the details of injuries of very specific crashes, was used over the past two years to analyze the scenarios. 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.). 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 lanes – 37 cases

Lead vehicle stopped and *vehicle turning* scenarios have been investigated for patterns of injury mechanisms. The third scenario, *vehicle changes lanes* has been analyzed as a case study review.

To date, 59 case studies involving *lead vehicle stopped* have been analyzed. The CIREN database revealed that the most common serious injuries (AIS 3+) occurred to the thorax, followed by the abdomen, and lower extremities. Of the AIS 3+ injuries to the three regions above, lower extremity injuries accounted for 51% of all of the injuries and almost all of the were only AIS 3. 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 (Phase I) and CIREN (Phase II) 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.

To date, 160 case studies involving a vehicle turning in front of a 2nd vehicle have been analyzed. The CIREN database revealed that the most common serious injuries occurred to the thorax, followed by the head, and abdominal regions. Of the AIS 3+ injuries to the three regions above, serious thoracic injuries account for 47% of the injuries, while 35% were to the head, followed by 18% to the abdomen. In these cases, 86% of occupants were wearing a seatbelt, but the side airbag deployed in 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. Most of the severe injuries are happening in secondary impacts. For autonomous vehicle programming, we suggest investigating ways to prevent secondary impacts, optimally align energy absorbing vehicle structures to reduce impact forces experienced by the occupant, and reduce overcorrection by the driver following initial impacts.

Scenario 3, vehicles changing lanes or merging on a highway, yields many different outcomes. Complicated crashes involving multiple vehicles, multiple impacts, and diverse vehicle trajectories often occur. 37 cases were chosen to look into mechanisms of injury. AIS 3+ thorax injuries were found to occur most frequently. The thorax injuries were mostly rib injuries and had diverse injury mechanisms. Steering wheel, b-pillar, and belt restraint/webbing and buckle contact caused many of these thorax injuries.

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 and injury epidemiology. Lauren Eichaker has taken AAAM's

AIS certification course to better understand the rules of AIS coding and the field of injury epidemiology. She took and passed the AIS certification exam on September 12, 2016; she is now a certified abbreviated injury scale specialist (CAISS). This is proving to be useful on other ongoing projects in the center as well.

Dissemination of Results: Phase I study has been published in the Annals of Biomedical Engineering. Phase II findings are being submitted to *IEEE – Transactions on Intelligent Vehicles.*

Plans for next period**:** We plan to develop new research questions pertaining to the use of injury mechanism analyses for the design of autonomous vehicle behaviors. Also, CIREN is a database that contains only the most severe crashes and is comprised of data collected from 6 centers around the US. We are therefore working on applying epidemiological techniques to this data set in order to make our findings more robust and meaningful across the entire country.

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) and *TIP-Traffic Injury Prevention.*
Presentations **–** The results, findings, and implications of Scenarios 1 and 2 were presented at the Association for Automotive Medicine's student symposium in Waikaloa, HI on September 17, 2016. The title of the presentation was "Analysis of Injury Mechanisms and Outcomes within 2 Common Crash Scenarios: Implications for Autonomous Vehicle Behavior Design."
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/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: The primary goal for Year 3, Project 5 was to develop simulation models for vehicle to cyclist pre-crash interval.

Accomplishments: TASI at IUPUI has been working on four parallel activities since the start of the program. A summary of these activities are given below:

Activity 1. Create a driving simulation model of a pedestrian forward autonomous emergency braking (AEB).

Activity 2. Integrate the active safety sensing information in V2V study. Our idea is to link V2V and CIB capabilities together and let a cyclist AEB system tell other vehicles the presence of cyclists. If a vehicle can exchange the cyclist sensing information in real-time, the vehicle can get potential cyclist crash information before itself can sense the cyclist crash, and hence, have more lead time to respond to a potential crash and to improve safety. Four graduate students have been working on this problem. The cyclist AEB model will be used for vehicles to detect pedestrians and broadcast to other vehicles in V2V-AEB simulation.

Activity 3. Transfer the technology of the Computer-assisted Alcohol Infusion System (CAIS). The CAIS apparatus combines a physiologically based pharmacokinetic (PBPK) model of alcohol distribution and elimination with computer control of infusion pump rate to enable precise control of breath alcohol concentration over time. The precise alcohol level control and driving simulation provide the ideal environment for various types of drunk driving study. The device has been designed and successfully tested. NCAT is actively pursuing the collaborative research in drunk driving using CAIS and driving simulators, and technology transfer opportunities of CAIS with our UTC program partners.

Activity 4. Using a dataset developed from the Indiana State Police and linking it with Census information from the American Community Survey to find the incidence related to race, income and poverty status of pedestrians and drivers involved in crashes and the scope for AEB technologies to mitigate them.

Major findings or results:

Activity 1. A PreScan model of a Pedestrian/cyclist AEB system has been developed. The model uses the PreScan vehicle simulator provided by TASS International. The model describes the AEB performance based on the vehicle speed, pedestrian speeds, pedestrian sizes, the pedestrian motion direction relative to the vehicle motions, and lighting conditions. The goal of Activity 1 has been reached. A better approach is being studied. A pedestrian AEB model was developed based on hundreds of pedestrian AEB system tests conducted by TASI from another research project funded by our industry partner. A cyclist AEB model was developed based on hundreds of cyclist AEB system tests.

Activity 2. Develop sensor fusion methods to process the pedestrian information obtained from the sensors on multiple vehicles. A new clustering algorithm was developed to identify the pedestrians reported by multiple vehicles. To reduce the amount communication and computation work, methods were developed to combine the related information into single messages and processing them as single objects.

Activity 3. A report of the pilot study performed in the IUPUI TASI simulator using CAIS was prepared. The report has been turned into a manuscript for submission to the Research society for Alcoholism.

Activity 4. Preparing a conference “Smart Privacy for Intelligent Systems” to bring together representatives from industry, urban planning and administration, regulatory agencies and academia to identify workable regimes that strike an appropriate balance between data privacy and data usability in systems such as intelligent transportation and smart lighting.

During the first year, UMass reviewed different treatments that have been used to prevent right hook crashes with bicyclists.

Plans for next reporting period:

Activity 1. IUPUI will continue work on the second phase to transfer the cyclist AEB model generated from PreScan environment to the Realtime Technology driving simulator

Activity 2. Using the V2V-AEB simulation tool to develop new algorithms for data processing required for V2V-AEB operations, Expand the PreScan model to include large number of Vehicles and cyclists in the simulation.

Activity 3. Dr. O’Connor will continue to find collaborative partners to disseminate the alcohol control device in the alcohol related transportation study.

Activity 4. David Good and graduate student Brandon Taylor are nearing completion of linking ACS with the police crash reports. In October 2015 IU School of Public and Environmental Affairs will be hosting a 2 day workshop on "Smart Privacy for Intelligent Systems." This workshop will bring together representatives from industry, urban planning and administration, regulatory agencies and academia to identify workable regimes that strike an appropriate balance between data privacy and data usability in systems such as intelligent transportation and smart lighting. Organizers include Beth Cate and David Good (IU Bloomington).

Products:

Publications, conference, papers, and presentations:

Kai Yang, Chao Liu, Jiang Yu Zheng, Lauren Christopher, Yaobin Chen, "Bicyclist Detection in Large Scale Naturalistic Driving Video Comparing Feature Engineering and Feature Learning," revised for publication in *IEEE Transactions on Intelligent Transportation Systems*, 2016.

Lopez, A., Sherony, R., Chien, S., Li, L., Yi, Q., Chen, Y., and Sherony, R. "Certainty and Critical Speed for Decision Making in Tests of Pedestrian Automatic Emergency Braking Systems," Accepted for publication in *IEEE Transactions on Intelligent Transportation Systems*, August 2016.

Libo Dong, Stanley Chien, Jiang-Yu Zheng, Yaobin Chen, Rini Sherony, Hiroyuki Takahashi, "Lighting Model for Testing Pedestrians Automatic Emergency Braking," in *Proc. 2016 SAE World Congress*, Detroit Michigan, April 6, 2016.

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 has been providing the PreScan vehicle simulation software to IUPUI for the development of the simulation model and pedestrian CIB and V2V 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 and AEB sensing enables the transmission of the detected pedestrians and cyclist information to other vehicles that potentially make the other vehicle get information early enough to avoid the cyclist 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 cyclist AEB modeling activity provides a pedestrian collision imminent braking model for real vehicles. This simulation model provides a realistic reference for the development and improvement of new cyclist AEB systems. Our new cyclist detection methods based on motion in the real driving video data not only identify the human walking characteristics, but also contrast to the motion of other scenes. In details, HOG based leg chain detection and Corner based non-smooth motion methods are proposed and examined in order to increasing the detecting accuracy. (2) TTC computation using video data also utilize motion information in the video to avoid vehicle recognition in the video such that a fast and accurate function to avoid vehicle collision can be achieved. (3) We developed the first method to investigate light distribution in night from collected the naturalistic driving video in a city.

On the development of transportation workforce development: Five IUPUI Masters students in the Department of Electrical and Computer Engineering have been working on this project as part of their graduate degree requirements. One PhD student played major role in the algorithm development. Two master students have been involved in the driving video database development and server side programming. Fifteen master students participated in a term project to evaluate the performance and accuracy of our pedestrian detection. Three graduate students and two undergraduate students have selected driving video processing as their independent study course. Five undergraduate students have also participated in the term projects to numerically evaluate the algorithm and method based on sampling videos. One graduate student at IU-Bloomington has been involved as well. On technology transfer: IUPUI is actively pursuing the transfer and dissemination of the CAIS technology to a Driving simulator company and driving simulation community. 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)

Changes or Problems: This investigation has concluded.

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, Privacy-preserving, and Efficient Communication Framework to Support Crash-Imminent Safety Situations

Accomplishments: Our efforts have focused on investigating a secure, privacy-preserving, and efficient communication framework for vehicular networks. In addition to the last year investigations where we were focusing on achieving the confidentiality of vehicular communication, this year we are tackling two other important shortcomings in the Dedicated Short-Range Communications (DSRC) suite of standards: privacy-preservation and efficiency:

For achieving the needed location privacy, our research proposes a scheme to hide the changing of pseudonyms in Public Key Infrastructure (PKI) to prevent eavesdroppers from easily linking the used single pseudonym with the vehicle's identity. We propose the idea of the vehicle creating 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. The numerical evaluation of our scheme shows that the use of a different authentication gives comparable performance to that of the basic authentication in terms of computation time, storage cost, and number of handled vehicles.

Our second proposal focuses on the efficiency of vehicular communications. To overcome the heavy authentication load on the wireless access and the existing Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)-based schemes' inefficiency in dense scenarios where a large number of users compete for the medium, we develop a new cooperative beaconing strategy: Grouping for Beaconing Efficiency Enhancement (G-BEE). In G-BEE, vehicles dynamically form secure authenticated groups with their leadership roles being decided in a decentralized fashion. In this way, the main load of Vehicle-to-Infrastructure (V2I) beaconing is assigned to the group leader. This transforms the problem of medium access from a dense network of short sessions into one with a sparse network of longer sessions, the ideal setting for CSMA/CA. In order to not compromise the security of the created groups, we introduce a simple and an enhanced version of G-BEE to tackle two levels of authentication-overhead omission. To investigate the gain of our strategies, we build Bianchi, D/M/1, and D/M/1/1 Markovian analytical models. The numerical evaluations show that both G-BEE versions outperform the classical individual scenario. Furthermore, the enhanced grouping form achieves higher gains in terms of maximum availability, delay rate, collision rate, drop rate, and throughput.

Products: ***Publications:***

Y. Feng, S. Al-Shareeda, C. Emre Koksal, and F. Ozguner, "G-BEE: Grouping for Beaconing Efficiency Enhancement in vehicular networks", submitted to the IEEE Transactions on Vehicular Technology, 2016.

Collaboration: The second research track is a result of collaboration with Prof. C. Emre Koksal.

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, the joint operation across DSRC and radar bands, and efficient channel handoff schemes.

Accomplishments: During this reporting period, we investigated the feasibility of using the 79GHz band jointly with radars co-located on the vehicles. The specific objective of our study was to perform a comparative analysis of resource allocation methods in the radar band so that communication can be sustained while maintaining the baseline performance of the radar system, as if the radar system were operating on its own. We developed a communication protocol to enable establishment, maintenance, and control of the communication actions in the radar band with the assistance of the DSRC system. Our simulation studies have revealed the following:

1. Cooperative techniques employed by the radar system ensures that there are spectral resources left to sustain communication among LoS vehicles.
2. The spectral resources made available through proposed methods significantly improve the communication performance in bandwidth and latency despite high mobility of vehicles and channel uncertainties.

***Dissemination*:** Two conference papers summarizing our research outcomes have been published in WiOpt and ACM CarSys conferences.

***Next reporting period*:** Improved simulator developed to assess the performance of joint radar and communication systems, with an emphasis on channel modeling.

Products:

You Han, Eylem Ekici, Haris Kremo, and Onur Altintas, "Optimal Spectrum Utilization in Joint Automotive Radar and Communication Networks," Proceedings of WiOpt 2016, Tempe, AZ, May 2016.

You Han, Eylem Ekici, Haris Kremo, and Onur Altintas, "Automotive Radar and Communications Sharing of the 79-GHz Band," Proceedings of ACM CarSys 2016, New York, NY, October 2016.

Impact: Development of the principle discipline: The effort during this reporting period builds upon our previous findings that revealed that long-held beliefs about the use of 802.11p protocol as a very good, real-time communication alternative were indeed unfounded. Our new studies show that it is possible to utilize radar bands allocated for vehicular radar systems to communicate data across vehicles. The resulting increase in the available bandwidth is significant enough to warrant further investigation of practical methods to jointly utilize this channel, and also to model the radar band for the purpose of communication.

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," submitted for possible presentation at the 2017 TRB annual meeting.

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

Changes or Problems: Nothing to report.