CrIS | Crash Imminent Safety UTC

Program Progress Performance Report

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

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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 **six interconnected research projects** that address three research strategies: driver interaction; pre-crash simulation; human physiology. **Each project has stand-alone research objectives described in detail in each project section of this PPPR**.

The Center continues to produce newsletters regularly and has published a colorful Annual Report which was first distributed at the end of October.

Center researchers attended and made presentations at numerous technical conferences including the Annual TRB Meeting, the "Annual Safety Summit" in Washington D.C. organized by CMU, the IEEE Intelligent Vehicle Symposium and the IEEE ITS Conference.

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 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, and the Mid-Ohio Regional Planning Commission (MORPC). At Ohio State, collaborations with DURA, Ford Research, and Renault 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 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 2017. 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-*Advanced Graduate Training:* ECE 7855 Large Scale and Cyber-Physical Systems (Au 2016): Decentralization, hierarchy and their effects on modeling, stability analysis, and optimal controller design. Hybrid system based modeling and design of Cyber-Physical Systems.

Activity 3 – *Senior Design Projects:* At IUPUI, a graduate student and a team of 4 undergraduate students worked on their senior design project by creating a driving simulator for vehicle road departure using naturalistic driving video data. They have learned state of the art research issues about constructing the 3D model based on the camera image and Lidar distance sensing. They also learned the real time coordinate transformation based on the vehicle speed and steering angle.

Activity 4-*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; Guotao Xie, a Ph.D. student from the State Key Laboratory of Automotive Safety and Energy, Tsinghua Univ. China.

Facilities and Experiments—K. Redmill

- OSU automated vehicle fleet has been improved with the development of a three-vehicle convoying and lane change experiment. Existing partially-automated and fully-automated vehicles were equipped with the required communications hardware and the software algorithms to perform partially automated lateral maneuvers (lane changes) in an extension of the cooperative adaptive cruise control scenario. This vehicle group is to be used further for safety critical scenarios that involve partial autonomy and partial human control.
- We are automating an additional passenger sedan for longitudinal automation and highway cooperation scenarios, and updating the hardware on our fully-automated DARPA Urban Challenge vehicle in order to improve the computatuonal power for futre applications.
- IUPUI renovated the laboratory and office space for the Tracsportation Active Safety Institute where the UTC research projects are being conducted. They have also added a 2200 sq ft laboratory off campus that allows vehicles to drive in for research purposes. The lab and its equipment are used for advanced human-vehicle interfaces evaluation and ADAS reseach and development.
- IUPUI has worked with industrial partners for several large-scale evaluation of advanced driver sensing system. Over a hundred undergraduates and graduate students were involved in this project in data collection and data processing. They have worked with another industry partner for the road/roadside image sampling over all United States for study of vehicle road-departure prevention. 15 graduate and undergraduate students were involved in data gathering, data processing, image processing, and database development.

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 4: 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.

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: Nothing to report.

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 4: 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 first half of Year 4, we are continuing to improve our model-building and estimation efforts, and refining possible closed-loop impact through future active safety systems that make decisions based on the insight generated by human driver models. The team at NCA&T is currently focused on predictive control of fully or partially autonomous vehicles in highway driving scenarios. In addition, the sensitivity analysis of Hidden Markov Models using simplified matrix-based efficient algorithm for computing the sensitivity function is proposed.

Accomplishments: CrIS UTC researchers are studying different methods of capturing driver behavior in computational and functional models. The following models are developed as a means of understanding and quantifying human driving behavior, to be used in ADASs or partial/full automation applications.

1. **Sensitivity Analysis of Hidden Markov Models**

Driver behavior modeling plays a significant role in the development of Advanced Driver Assistance Systems (ADAS) for assisting drivers in different driving scenarios. One of the scenarios where high numbers of traffic accidents occur is at road intersections. It is vital to develop driver behavior models near intersections in order for the ADAS to plan a proper action in avoiding accidents. In our work, driver intention estimation near a road intersection using discrete hidden Markov models (HMM) based on the hybrid-state system (HSS) framework is presented. In the HSS framework, the vehicle dynamics are represented as a continuous-state system (CSS) and the decisions of the driver are represented as a discrete-state system (DSS). The continuous observations from the vehicle including speed and yaw-rate, are used by the proposed technique to estimate the driver's intention at each time step. In this work, the speed and yaw-rate are discretized in such a way that the important features about the driver's intention to go straight, turn left, turn right or stop at the intersection and are converted into categorical symbols. The models are trained and tested using naturalistic driving data obtained from the Ohio State University, in an experiment with a sensor equipped vehicle that was driven in the streets of Columbus, OH. The proposed approach shows promising accuracy in estimating the driver's intention when approaching an intersection.

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 done 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.

2. Personalized Highway Driving Assistance System

Most of the ADASs currently available are focused on safety, and they generate default maneuvers independent of the driver or passengers. However, different drivers have different driving styles and a pre-planned maneuver may not satisfy everyone. Thus, in this study it is proposed that drivers' styles be incorporated into the ADAS without compromising vehicle safety, to increase the drivers' satisfaction and comfort in autonomous vehicles.

In this study, a highway driving assistance system, which performs per the driver's preference, is presented. This system consists of a data driven driver model integrated with a model predictive controller, and operates in three modes: path following, car following and lane change. The driver model is trained using naturalistic driving data and can emulate different driving styles. The MPC ensures safety by enforcing a set of constraints on the vehicle state. The system can detect and handle driving situations where vehicle safety is the priority, specifically in the presence of multiple surrounding vehicles. In addition, the system can make a lane change decision if it will satisfy the drivers' preference.

The proposed method is simulated for the longitudinal control of an autonomous car in two different scenarios. The results demonstrated that the proposed approach can handle both light and congested traffic situations. These results show that the proposed approach performs well on the task it was designed for, that is, to learn from driving data and emulate driving styles while ensuring safety.

3. Collision Avoidance System with Fuzzy Danger Level Detection

To ensure the safety of the vehicle in near crash or crash scenarios, a collision avoidance system for safe trajectory planning of lane change events is proposed in our research. This collision avoidance system modifies the lane change trajectory based on the danger level of the event. A fuzzy danger level detection system is designed using naturalistic near crash events to determine a realistic risk level of a dangerous scenario. The training data is derived from the 100 car naturalistic driving data. The data is pre-processed and the samples with missing or invalid data are removed. We chose two groups of sample data, according to the feature "fault". Then, additional features are used to develop the structure of fuzzy danger level detection model. The model is using to produce a danger level basis for the crash avoidance system by using the measurements: velocity, yaw rate, accelerations in lateral and longitudinal. Afterwards, a model predictive controller generates safe longitudinal and lateral trajectories for the lane change maneuver based on the computed danger level.

Moreover, an additional feature in the proposed collision avoidance system is a fault determination classifier, which is trained by the naturalistic data to determine whether the subject vehicle or the surrounding vehicle is responsible for the near crash/crash event. In this work, the problem is formulated as a classification task and Extreme Gradient Boosting algorithm is used for identifying the responsible driver who is at fault. The classifier is tested and the results show that the technique can provide an additional feature as fault belonging with high accuracy. The results of this classifier also can help to further adjust the performance of the proposed collision avoidance system.

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. (2017). Distributed Model Predictive Control of Spatially Decoupled Systems Using Switched Cost Functions. arXiv preprint arXiv:1606.02224.

Liu, P., Ozguner, U., & Zhang, Y. (2017). Distributed MPC for cooperative highway driving and energy-economy validation via microscopic simulations. *Transportation Research Part C: Emerging Technologies*, 77, 80-95.

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

Amsalu, S. B., & Homaifar, A. (2016, August). Driver behavior modeling near intersections using Hidden Markov Model based on genetic algorithm. In *Intelligent Transportation Engineering (ICITE), IEEE International Conference on* (pp. 193-200). IEEE.

Amsalu, S. B., & Homaifar, A., "Driver Intention Estimation via Discrete Hidden Markov Model". IEEE International Conference on Systems, Man, and Cybernetics, October 5-8, 2017, Banff Center, Banff, Canada, (submitted).

Amsalu, S. B., & Homaifar, A., "A Simplified Matrix Formulation for Sensitivity Analysis of Hidden Markov Models," MDPI Journal of Algorithms, (submitted).

Ramyar, S., Homaifar, A., Karimoddini, A., & Tunstel, E. (2016, October). Identification of anomalies in lane change behavior using one-class SVM. In *Systems, Man, and Cybernetics (SMC), 2016 IEEE International Conference on* (pp. 004405-004410). IEEE.

Ramyar, S., Homaifar, S. M. Salaken, S. Nahavandi, & Kurt, A. (2017). A Personalized Highway Driving Assistance System. In *2017 IEEE Intelligent Vehicles Symposium, Proceedings of*. IEEE.

Wang, Z., Ramyar, S., Salaken, S., Homaifar, A., Nahavandi, S., Karimoddini, A., "A Collision Avoidance System with Fuzzy Danger Level Detection". IEEE Intelligent Vehicles Symposium. 2017 (accepted).

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 driving data collected in Ohio State University, and samples from larger naturalistic driving studies.

The NCAT team has collaborated with Prof. Saeed Nahavandi and his PhD student, Syed Moshfeq Salaken from Deakin University, Australia. Salaken visited ACIT Institute in January 2017 and worked with students in developing machine learning models from naturalistic driving data.

Impact: **HMM Sensitivity analysis:** The sensitivity analysis of Hidden Markov Models helps in finding the weaknesses of this technique, which in turn leads to the development of more accurate and robust models for human drivers.

Personalized highway driving assistance system:
In this system, the highway driving maneuvers are executed per the driver's preferences while maintaining safety and road regulations. This study can be extended to other highway and urban driving scenarios. Ultimately, the results can help develop more consumer friendly ADASs leading to an increase of trust and sales of autonomous vehicles.

Collision avoidance system with fuzzy danger level detection and fault determination:
The results of this study will improve the performance of collision avoidance systems by providing additional insight on the danger level of a near crash event and the responsible driver.

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 4: 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 Awareness 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. Based on this work two new projects have been awarded by NASA. One is on Human-Autonomy Teaming with Georgia Institute of Technology, and the other is a Resiliency Trade Space Study of detect and avoid automation.

Products:

Refereed Conference Proceedings

Fariadian, A. B., Annaswamy, A. M. and Woods, D. D. (2017). Bumpless Reengagement Using Shared Control, 20th IFAC World Congress, July 2017.

Other Publications

Woods, D. D. (2016). Risks of Autonomy: The Future is Already Here and It Doesn't Work as Advertised. International Symposium Human Factors in Automation, TNO, Soesterberg, The Netherlands, October 12-13, 2016. http://csel.org.ohio-

state.edu/videos/Woods_TNO_Talk.mp4

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: Nothing to report.

Project 4. Bioinjury Implications of Pre-crash Safety Modeling and Intervention
Investigators—Bolte (OSU), lead; Weisenberger (OSU)

Major Goals - Year 4: 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 population based, 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 II. A thorough CIREN search revealed the following number of cases for each scenario:

a. Lead vehicle stopped (LVS) – 59 cases
b. Vehicle turning (Near Side Impact (NSI)) – 160 cases
c. Vehicle changes lanes (Changing Lanes on Highway (CLH)) – 37 cases

Lead vehicle stopped (LVS) and *vehicle turning (NSI)* scenarios have been investigated for patterns of injury mechanisms. The third scenario, *vehicle changes lanes (CLH)* has been analyzed as a case study review.
To date, 59 case studies involving *lead vehicle stopped (LVS)* 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.

For the LVS cohort, the study population was compared to both the population of the US and the average population of the six catchment areas of CIREN and the variations were noted. People over the age of 65 are over represented and people under the age of 18 are underrepresented compared to both the catchment area population and the population of the US census. Fewer women than the CIREN average population and the average of the US are present in this cohort. Additionally, the Hispanic/Latino identifying population is smaller than that of the US census, but falls into the range of the average population of the CIREN catchment areas. High school graduates are over represented within this population.

To date, 160 case studies involving a vehicle turning (NSI) 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.

For the NSI cohort, the study population was compared to both the population of the US and the average population of the six catchment areas of CIREN and the differences were noted. Overall, the study population consisted of more elderly people (age 65+) than the US population and the population of the catchment areas of CIREN. There are fewer Hispanic or Latino identifying people within the CIREN and study populations compared to the US average, but the study population compares well to the CIREN population average. There are more female persons within the study population compared to both the US average and the CIREN catchment area average. People that achieved a level of education of high school or higher are present at a higher population within the study population.

The fact that both the LVS and NSI populations consisted of more elderly (age 65+) people than the US Census and average population of the catchment areas of CIREN highlights the need for improving safety technologies for this at-risk population.

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: Lauren Eichaker has been working with her committee to broaden and strengthen her statistical analyses and application of epidemiology techniques to her data set.

Dissemination of Results: Scenario 3 findings have been submitted to IEEE Conference on Control Technology and Applications.

***Plans for next period*:** We continue planning 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 continually 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. One report on Scenario 3 was submitted to IEEE Conference on Control Technology and Applications, Scenarios 1 and 2 will be submitted *to IEEE – Transactions on Intelligent Vehicles* (a new section of IEEE that will begin publishing in 2016).
***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. Lauren's committee member (Amy Ferketich) in epidemiology has provided guidance on the use of epidemiology and statistics to quantitatively describe her results.

***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 4: The primary goal for Year 4, Project 5 was to develop simulation models for vehicle to cyclist pre-crash interval.

Accomplishments: TASI at IUPUI has been working on three 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. The cyclist AEB model will be used for vehicles to detect bicyclists and broadcast to other vehicles in V2V-AEB simulation. Four graduate students have been working on this problem. The communication exploration problem for a large number of vehicles is studied. The fusion of information of vulnerable road users sensed from many surrounding vehicles was studied.

Activity 3. Develop the automatic emergency pull over driving simulation for drivers who are losing driving capabilities due to medical emergencies (e.g., heart defibrillation).

Major findings or results:

Activity 1. A cyclist AEB system model is being developed. Over 70 performance test data of a 2016 vehicle bicyclist AEB collected by IUPUI is used for the model development. The model describes the AEB performance based on the vehicle speed and bicycle speeds. The goal is to find a systematical method to describe and improve the bicycle AEB performance.

Activity 2. Develop sensor fusion methods to process the pedestrian/cyclist information obtained from the sensors on multiple vehicles. A new clustering algorithm was developed to identify the pedestrians/cyclist reported by multiple vehicles. A hierarchical clustering method was developed. Methods were developed to reduce the unnecessary message sending to avoid communication load and computation work. Two papers will be published in 2017 ESV conference in June 2017.

Activity 3. For avoiding the vehicle crash caused by a driver losing consciousness due to various medical reasons during driving, a Vehicle Automatic Emergency Pull-over (AEP) strategy is designed and implemented on a driving simulator. A moving vehicle equipped with AEP system can automatically pullover on the roadside safely when the driver is considered incapable of driving. AEP uses intelligent decision making on top of available vehicle active safety features such as Lane Keeping Assist, Blind Spot Monitoring, Adaptive Cruise Control, Automatic Lane Change and Automatic Emergency Braking. A paper is accepted to be published in the 2017 FAST Zero conference to be held in September 2017.

Plans for next reporting period:

Activity 1. IUPUI will continue work on the development for cyclist AEB model.

Activity 2. IUPUI will continue the work of V2V-AEB integration.

Activity 3. IUPUI will be perfecting the AEP system by standardizing the interface of all active safety system modules. They will enable the implement other automated driving simulation development.

Products:

Student Graduations:

A student graduated with Master of Science in Electrical and Computer Engineering in December 2016.

A student has passed his thesis exam and will graduate with Master of Science in Electrical and Computer Engineering in May 2017.

Publications, conference, papers, and presentations:

Domenic Belgiovane, Chi-Chih Chen, Stanley Chien, Rini Sherony, “Surrogate Bicycle Design for Millimeter-Wave Automotive Radar Pre-Collision Testing," IEEE Transactions on Intelligent Transportation Systems, Online ISSN: 1558-0016, Digital Object Identifier: 10.1109/TITS.2016.2642889

Wasif Javaid; Yaobin Chen; Stanley Chien, Design and Implementation of Vehicle Automatic Emergency Pull Over Strategy Using Active Safety Systems on a Driving Simulator, abstract accepted by Fourth International Symposium on Future Active Safety Technology Towards Zero Traffic Accidents (Fast-zero), Nara, Japan, September, 18-22, 2017.

Qiang Yi, Stanley Chien, Li Fu, Lingxi Li, and Yaobin Chen, Rini Sherony, “Clothing color of surrogate bicyclist for pre-collision system evaluation, accepted 2017 IEEE IV conference, June, 2017 California.

Jie Xue, Zhi Huang, Stanley Chien, Yaobin Chien, “A Hierarchical Clustering Analysis (HCA) for Pedestrian Position Identification in Autonomous Driving with Vehicle-to-Vehicle Communication.” Abstract accepted by 25th International Technical Conference on Enhanced Safety of Vehicles (ESV) June 5-8, 2017, Detroit, USA.

Shalabh Rakesh Bhatnagar, Stanley Chien, Yaobin Chen, “Effect of delay in V2V-AEB system and ways to handle it,” abstract accepted by 25th International Technical Conference on Enhanced Safety of Vehicles (ESV) June 5-8, 2017, Detroit, USA.

Terence Haran, and Stanley Chien, “Infrared Reflectivity of Pedestrian Mannequin for Autonomous Emergency Braking Testing,” 2016 IEEE ITSC conference, Nov 1-4, 2016 Rio, Brazil.

Bo Tang, Stanley Chien, Zhi Huang, and Yaobin Chen, “Pedestrian Protection Using the Integration of V2V and the Pedestrian Automatic Emergency Braking System,” 2016 IEEE ITSC conference, Nov 1-4, 2016 Brazil.

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. Fifteen graduate and undergraduate students participated to the data processing of 44000 vehicle road/roadside photos for road departure study. 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 4: 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: Throughout the last years, our main focus has been on investigating algorithms and approaches to secure, preserve privacy, and enhance efficiency of the vehicular communications. Our developed approaches overcome the shortcomings of the adopted Public Key Infrastructure (PKI) framework in the Dedicated Short-Range Communications (DSRC) suite of standards. Besides our previous confidentiality and secrecy of communication research, during the last six months, we have continued tackling the:

1. **Preserving Location-privacy of Vehicles**. We propose a scheme to hide the changing of certificates/pseudonyms in PKI to prevent eavesdroppers from easily linking the used single pseudonym with the vehicle's identity. The idea is to have vehicles create dynamic mix zones using an alternative super anonymous authentication scheme to hide their pseudonym change. Once the change occurs, 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 its effectiveness and how it gives comparable performance to that of the basic authentication in terms of computation time, storage cost, and number of vehicles.
2. **Efficiency of vehicular communications**. To overcome the heavy authentication load on the wireless medium the inefficiency of the adopted Carrier Sense Medium Access with Collision Avoidance (CSMA/CA) schemes in dense scenarios, our second track of research focuses on building a new cooperative beaconing strategy: Grouping for Beaconing Efficiency Enhancement (G-BEE). We use the concept of grouping to offload the main load of Vehicle-to-Infrastructure (V2I) beaconing from all network users to only group leaders. 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. We introduce two versions of G-BEE: simple and enhanced to deal with two levels of authentication-overhead omission. We investigate the gain of our strategies by building stochastic analytical models. The numerical evaluations show that both G-BEE versions outperform the classical individual scenario and achieve higher gains in terms of maximum number of vehicles, delay rate, collision rate, drop rate, and throughput metrics.

Products: ***Publications:***

Al-Shareeda, S., & Özgüner, F., "Preserving location privacy using an anonymous authentication dynamic mixing crowd," in proceedings of the IEEE 19th International Conference on the Intelligent Transportation Systems (ITSC2016), pp. 545-550, 2016.

Feng, Y., Al-Shareeda, S., Koksal, Emre C., Özgüner, F., "G-BEE: Grouping for Beaconing Efficiency Enhancement in Vehicular Networks," submitted to the IEEE Transactions on Mobile Computing, 2017.

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 4: 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*:** A journal paper has been published summarizing there results.

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

Products:

Han, Y., Ekici, E., Kremo, H., Altintas, O., "Vehicular Networking in the TV White Space Band, " to appear in IEEE Vehicular Technology Magazine, February 2017.

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: Nothing to report.

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.