CrIS | Crash Imminent Safety UTC

THE OHIO STATE UNIVERSITY

Program Progress Performance Report

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

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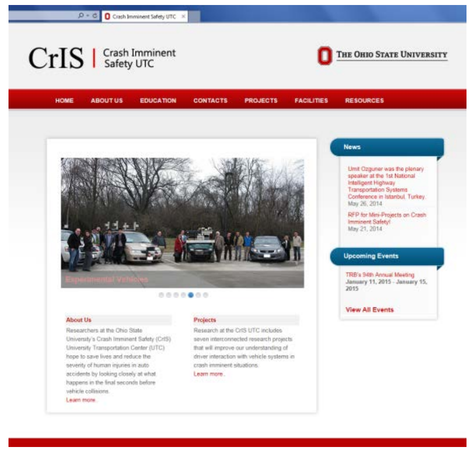
CENTER FOR AUTOMOTIVE RESEARCH

Overview

The primary research objective of the Crash Imminent Safety University Transportation Center (CrIS UTC) is **to improve understanding of driver interaction with vehicle systems in crash imminent situations, with a goal of substantially improving safety.**

We have executed seven interconnected research projects that address our four research strategies: driver interaction with autonomous vehicles; pre-crash simulation and verification; human physiology and behavior; and policy implications and dissemination. Each project has stand-alone research objectives described in detail in each Project section of this PPPR. CrIS UTC also has many accomplishments:

- Developed the CrIS UTC Website
- Membership in the Council of University Transportation Centers
- Released its inaugural Newsletter, to be issued quarterly
- Opened its new facility to house vehicles and driverless vehicle laboratories;
- Distributed an RFP for mini-projects on Crash Imminent Safety, resulting in two additional research projects, one based at Ohio State and one at IUPUI;
- Took the lead in organizing the 25th IEEE Intelligent Vehicles Symposium held in Dearborn, Michigan, June 8-11, 2014.
- Recruitment of the CrIS UTC External Advisory Board;
    - James Barna, Ohio Department of Transportation;
    - Steven Feit, Honda Research and Development;
    - William Windsor Jr., Nationwide Insurance;
    - Dimitar Filev, Ford Motor Company;
    - Charles Gulash, Toyota Collaborative Safety Research Center
- CrIS UTC has had an impact engaging new PhD students that are interested in transportation safety related issues. It has also created interest among undergraduate students considering graduate programs in transportation related fields.



http://citr.osu.edu/CrIS/
Figure 1. CrIS UTC Website

Education and Outreach—F. Ozguner

Primary Goal: To transfer the knowledge gained through CrIS research efforts to the next generation of ITS engineers and for use to develop policies related to autonomous vehicle technologies through the development of four distinct education and outreach activities:

Activity 1-*STEM Summer Program:* Every year, OSU offers a Women in Engineering (WiE) RISE camp for high achieving high school students. This year students participated in a week-long workshop developed by graduate students and staff at CrIS UTC where they learned 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.

Students were presented with a broad overview of how autonomous vehicles work, along with engineering problems that need to be solved. They were then divided into teams to program sparki, acting as a surrogate vehicle, to behave like a self-driving car. Each day, students were given a different task to complete, including precise navigation, line following, obstacle avoidance, caravanning and intersection handling. The capstone project was to incorporate all of these concepts into one course. In just five days students learned how to program their robots to stay on the road (follow a line), avoid hitting other "cars" on the course, and safely navigate through an intersection.

Activity 2: *"Hands on" courses that introduce undergraduate students to AVs and the simulator environment.* During spring 2014, nearly twenty graduate and undergraduate students participated in the Autonomy in Vehicles (ECE5553) course at The Ohio State University. The course focused on autonomy analysis and development of modern road vehicles. In this section, students were the first to experience a new set of laboratory experiments designed to explore different aspects of intelligent transportation systems in a scale robot indoor test-bed and on full-scale hardware. The experiments involved first testing new control strategies, including lane keeping, convoying and traffic light handling, in a Player/Stage software simulation before utilizing the CITR SimVille indoor test-bed. In prior years, only the simulation portion was performed, but with sponsorship from CrIS, the students were able to get more hands on experience with real robots.

Two additional experiments were added as well. Using the CITR driving simulator, students collected data from several people as they drove through two lane change maneuvers. After analyzing this data, students created a simulated vehicle which would perform similar maneuvers in a human-like manner. For the final experiment, through the help of a grant from the DENSO Foundation, students used DENSO wireless safety units (WSU), mounted on two golf carts, to receive and process vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) messages to navigate traffic light and stop sign intersections. Speed advisors were created and displayed on an advanced driver assistance system (ADAS) display to tell the driver the speed required to pass through the traffic light during a green phase. A similar stop/go advisory was generated for a stop sign intersection to tell the driver when the intersection was clear of other vehicles.

Activity 3: *Undergraduate Research.* One of the undergraduate student groups in the summer term of ECE 4900 (Senior Capstone Design) developed and implemented the basic mechanical and electronic hardware for an automated golf cart. Additional individual undergraduate research projects and capstone groups are working on the sensing, communications, control, and behavior software for that platform.

- Other capstone groups have worked on related activities, including localization and data collection using both robots and passenger vehicles.
- We have provided cooperative automated, semi-automated, and mixed traffic demonstrations on our test vehicles.

Activity 4: *Roundtables with industry and community leaders to better understand the implications, and needed regulations, for AV technologies.* The policy analytics project is designed to understand how safety, crashes, and autonomous vehicles are discussed in the policy realm and what this tells us about the development of the technology, regulatory discussions, and barriers to the adoption of the technology. The first investigative task was identifying the ways that this technology is talked about in the corpus. Using the initial empirical results, the research team is continuing to develop their research questions and analyze the data. For their initial paper, the research team is focused on how safety is discussed. There is empirical evidence indicating that there has been a shift from a human-based safety regime to one based on technologies. There are two possible hypotheses as to the reason for this. The first is that the limits of human-based safety regulations and programs have been reached. The second hypothesis is that the advances in technologies have made technology-based safety much more possible. The research is still being done to determine which of these hypotheses is correct. *The results will be presented at a workshop/seminar for engineers and policymakers to be held in January 2015.*

Products

Lab manual: "Understanding Self-Driving Car Operation by Training 'Sparki' the Robot: A Short Course for High School Students"

Lab manual: "ECE 5553 Autonomy in Vehicles," Spring 2014

Facilities and Experiments—K. Redmill

Recent enhancements of facilities and resources include:

- Two local driving simulators have been linked and basic testing appears successful. We will not be expanding to link and test remote simulators that aren't on the same local area network.
- We have completed the development of a V2X laboratory (funded by the Denso Foundation) providing DSRC radio hardware, as well as robots and diagnostic equipment that can be used for testing and implementing wireless communication based safety, sensing, and autonomous systems.
- Undergraduate research students have implemented a vehicle cab buck for the small 3-display driving simulator housed at the CITR facility.
- We have occupied our new 1300 square foot garage with a paved securely fenced area, located behind the UTC site, and it is now available for vehicle preparation, equipment maintenance and experiment development.
- We have begun hardware preparations of a new experimental vehicle platform (a Toyota Prius). This was not purchased using UTC funds, but will be used in UTC research and demonstration activities.

Databases: We continue to acquire and understand databases for use by UTC researchers containing either recorded naturalistic driving or accident/incident reports and statistics.

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)

Accomplishments

Progress toward stated objectives and goals: The primary goal/objective for Year 1 for Project 1 is the networking of driving simulators across the institution in the CrIS UTC. We have made some progress toward this goal, but much remains to be done. Initially, it was determined that the simulators would be added to the network one at a time, and an order for adding simulators was created. At the present time, two simulators (one desktop, one motion platform) are networked and communicating in a common scenario, with the driver in each simulator able to see a representation of the other vehicle. Several problems needed to be overcome to accomplish this goal, most involving phantom representations in one of the simulations that had not been programmed. We are proceeding at this point with adding a third simulator to the network.

This effort has required the establishment of VPN connections across laboratories to allow safe and secure access among the universities and laboratories in the CrIS UTC. Navigating the VPNs has created some challenges in ensuring adequate speed and bandwidth for common simulations. Moreover, some of the simulators at partner universities are not currently connected to the internet, and this issue will need to be addressed before these simulators can join the overall networked simulation. Additional challenges involve differences in hardware and software across laboratories that impact the degree of transferability of scenarios.

UMass is in the process of upgrading to Windows 7 and adding a VPN at their site, both of which are required for connecting the RTI simulator at UMass Amherst with the RTI at Ohio State.

NCA&T has done the preliminary background study for the implementation of this project. A driving simulator has been ordered and student training will begin in October. In addition, two new PhD students have been recruited to work on Projects 1 (and 3). Additionally, NCA&T undertook a thorough literature review of Scenario Authoring**.**

The scenario design and authoring tool which we are going to use is SimVista, developed by Realtime Technologies Inc. for the desktop driving simulator. The SimVista uses Graphic User Interface (GUI), which allows for tile-based scenario design (as opposed to tedious text-based methods for others). Scenario control is achieved by two main groups of objects; sensors and markers. Sensors are mainly used to trigger actions of other objects, thereby controlling critical events, whereas markers provide reference points for dynamic objects (mainly vehicles and pedestrians). Ambient traffic is automatically generated using the “bubble-based” algorithm. Two concentric “bubbles” are created around the human driver such that the border of the smaller bubble is just out of the driver’s line of sight. New vehicles are placed randomly on the road network on the border of the larger bubble travelling toward the human driver.

Plans for next reporting period: We will continue to add additional simulators to the network, and will address challenges to timing and bandwidth limitations as they arise. UMass hopes to have the multi-simulator testbed in place in the next six months, and then design and run a pilot experiment during the last six months of the next reporting period. In addition, we are helping add to the functionality of SimDriver, an RTI software product, that will allow the partners in this UTC with an RTI simulator to provide the driver’s vehicle with the autonomous and semi-autonomous capability needed to evaluate the transfer of control from the automated driving suite (ADS) to the human driver and conversely. Also, NCA&T has ordered a driving simulator, and student training will begin in October.

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

Products

Nothing to report

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).

UMass Amherst and the Volpe National Transportation Systems Center have established a collaboration through Don Fisher’s role as a Faculty Fellow.

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. Students participating in the project include Nishan Noronha, Patrick Veith, Tyler Whitlock, Jillian Zhang, Katelyn Silveous, Diana Dumenova, and Sean Harrington (all undergraduates).

2) A currently underway effort with a faculty member at Ohio State to assess the question of "road rage" among drivers, specifically the factors that increase aggressive behaviors in driving.

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, Nishan Noronha, Tyler Whitlock, and Jillian Zhang.

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 has been a challenge to get the simulators at Ohio State and UMass Amherst to talk with one another. However, we have staff and students at each location dedicated to making progress on the problem.

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)

Accomplishments

Progress toward stated objectives and goals: The primary research objective for Year 1, Project 2 was the development of a multi-agent driver model for pre-crash human behavior understanding. Ohio State has developed the multi-agent models of the driver and the vehicle that can be used to inform the design principles for optimized autonomous vehicles. OSU CrIS UTC researchers are investigating different ways of capturing driver behavior in computational and functional models. The purpose of developing these models is to provide a means of understanding and quantifying human driving behavior for the computational aspects of current and future transportation systems, ranging from Advanced Driver

Assistance Systems (ADAS) to partial/full automation applications. Our focus is on crash-imminent and crash-possible scenarios.

Two major directions were pursued in the last reporting period to achieve the above-stated goals. Lane-change severity/danger and trajectory prediction models were built for human-driven vehicles; and discrete-state encoding schemes were investigated to better define performance and success of discrete-state models.

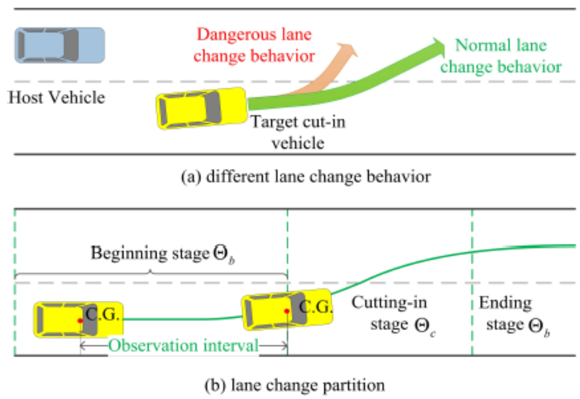


Figure 2. Lane-change classes and stages.

Model-development work focused on a trajectory prediction approach for a lane changing vehicle considering high level driver status. A driving behavior estimation and classification model was developed based on the Hidden Markov Model (HMM). In this work, the lane change behavior is estimated by observing the vehicle state emissions in the beginning stage of a lane change procedure, and then classified into the classes shown in the figure above, before the vehicle crossing the lane mark. The classifier is trained and tested using naturalistic driving data, which shows a good performance in classifying lane change behavior. This study was published in the Proceedings of 2014 IEEE Intelligent Transportation Systems Conference.

For the model and estimator analysis effort, an encoding scheme for discrete-state systems was developed as part of a hybrid-state hierarchy, which in turn can be used as a consistent norm for discrete states. Such a norm is demonstrated to be useful in hybrid-state estimation and driver-model accuracy. This study was accepted to appear in IEEE Transactions on Intelligent Transportation Systems.

NCA&T has conducted thorough literature reviews in the areas of *Hybrid State Systems for Autonomous Vehicle Control*; *Probabilistic Modeling of Mobile Agents*; and *Discrete-State Encoding in Hierarchical Hybrid-State Systems*. In addition to intersection scenarios, NCA&T is studying scenarios such as lane change, and stop sign. Also, we are investigating other machine learning techniques, including Dynamic Bayesian Networks, Learning Classifiers and conduct near-crash activities based on the selected methods. Modeling the driver behavior using manual Finite State Machines is also under consideration by employing the driving simulator for testing.

Training Opportunities: As part of CrIS UTC education activities, a new lab experiment for an OSU ECE course focused on human driver modeling. The Autonomy in Vehicles (ECE5553) students utilized our driving simulator to collect naturalistic driving data, and used the collected data to build path following and lane change models. The development of the students' effort closely resembled the larger undertaking that is part of CrIS UTC Project 2.

Plans for next reporting period: In Year 2, we plan to run experiments on our driving simulators to determine whether the model does indeed predict the optimized autonomous vehicle design with respect to the human operator.

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

Products

Refereed Journal Publications:

Fisher, D.L. and Strayer, D. L. (2014). Modelling situation awareness and crash risk. *The Annals of Advances in Automotive Medicine*, *58*, 33-39.

Kurt, A. (2014). Discrete-State Encoding in Hybrid-State Systems for Intelligent Vehicle Control and Estimation. To appear in *IEEE Transactions Intelligent Transportation Systems*. IEEE.

***Refereed Conference Papers*:**

Liu, P., Kurt, A., Ozguner, U. (October 2014). Trajectory Prediction of a Lane Changing Vehicle Based on Behavior Estimation and Classification. To appear in *The Proceedings of*, *Intelligent Transportation Systems*, *2014 17th International IEEE Conference on*. IEEE.

D. Opoku, A. Homaifar and E. W. Tunstel, "RFID-Augmentation for Improving Long-term Pose Accuracy of an Indoor Navigating Robot," the 2014 *IEEE International Conference on Systems, Man, and Cybernetics* (SMC2014) (Accepted in press).

Borowsky, A., Horrey, W., Liang, Y., Simmons, S., Garabet, A. and Fisher, D. L. (accepted). The role of working memory in driving related hazard anticipation. *Proceedings of the Human Factors and Ergonomics 2014 International Annual Meeting*, Chicago.

M. Gorji Sefidmazgi, M. Moradi Kordmahalleh, A. Homaifar, and A. Karimoddini, "Switched Linear System Identification based on Bounded-Switching Clustering," submitted to *American Control Conference* (ACC) 2015.

Databases and Models: The driver decisions as discrete states and vehicle dynamics as continuous states can be captured using hybrid-state system (HSS). In this work, HSS setting provides the architecture for the vehicular observations, and machine learning techniques such as Hidden Markov model (HMM) and the support vector machine (SVM) provide the mathematical relationship between the components of the HSS (Continuous and Discrete States). HMMs models were developed from the sequence of observations to estimate the driver decisions for every possible vehicle maneuver at the intersection as intra-subject analysis. In addition, an SVM based model for the driver at an intersection was developed.

As discussed in the April 2014 PPPR, CrIS researchers have access to a limited set of driving data to use in the model-building and training efforts. This dataset was analyzed in greater detail in this reporting period, and found to be limited in the sense that crash-imminent situations were not in large-enough numbers for significant model building and training. Using this smaller data set for initial guidance and proof-of-concept development, CrIS researchers have contacted the data steward for the SHRP2 Naturalistic Driving dataset, and the details of the collaboration and data sharing is currently being discussed. Using the relatively simplified public data from both SHRP2 and earlier naturalistic driving efforts, a lane change safety and trajectory prediction model was built, as discussed in the Progress section.

Collaborations

NCA&T continues working with the Ohio State team on developing a driver model at an intersection using Hidden Markov Model and Support Vector Machine.

Impact
Nothing to report.

Changes or Problems
Nothing to report.

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

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

Accomplishments

Driver attention and semi-autonomous vehicles

Five research programs were initiated and/or completed that focused on the role of attention in intelligent and semi-autonomous vehicles. First, it was shown that there are disrupting effects of in-vehicle glances on hazard anticipation when compared with drivers who glance continuously at the roadway. The development of in-vehicle systems that were able to detect latent threats could help reduce the risk of in-vehicle glances on hazard anticipation. Second, an analysis was undertaken of the duration of successive glances in a sequence of glances inside the vehicle, such multiple glances being typical of many of the in-vehicle tasks planned for semi-autonomous vehicles. Half received training to limit the duration of the highly risky, especially long glances. Half did not receive training. Several different types of in-vehicle tasks were used. The sequential analysis across trained and untrained drivers showed that the proportion of late sequence glances longer than a 2-second threshold among untrained drivers was almost double the number of such glances for the trained drivers, that the third and later glances were particularly problematic for some tasks, whereas all glances in a sequence (typically 6-7 glances to complete an in-vehicle task) were problematic when glancing at a GPS, and that training reduced the proportion of early and later sequence glances. The sequential analysis of in-vehicle glance data can be useful for researchers and practitioners, and has implications for the development and evaluation of training programs as well as for task and interface design. Third, given that maps produce especially long glances across all glances in a sequence, and given that maps are likely to be part of any semi-autonomous vehicle, it seemed important to determine whether an alternative display of the information in a map might decrease the frequency of especially long glances. Surprisingly, it did not do so. Thus, there is still much to do here.

Another research program considers estimating the driver's state, such as the degree to which the driver is distracted. Driver state estimation is central to managing transfer of control between the vehicle automation and the driver. If the driver is distracted at the time of transfer, safety will be compromised. We have developed several measures and algorithms to estimate driver state. These methods have been successful in detecting distraction as well as reduced alertness associated with fatigue and other impairments. Machine learning algorithms that we have investigated include Bayesian Networks, Support Vector Machines (SVM), Eye-Steering Correlation, and Random Forest. Our investigation considered the applicability, accuracy, and computational speed of these methods.

Transfer of Control Between the Driver and the Artificial Driving Suite (ADS): Current and proposed vehicular designs call for varying degrees of shared control of the vehicle between the human and ADS. In cooperation with other CrIS partners, an experimental methodology has been developed that will use a multi-monitor video output generated by the full scope simulator, but run on the desktop simulator to explore the ways that research participants interact with and manage transfer control with a simulated ADS. Smooth or bumpless transfer of control represents an essential design concern that must be addressed if vehicle automation is to enhance driving safety.

This work addresses several questions about bumpless transfer of control. 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; by resuming direct control or by re-tasking the ADS within a new limit of authority? These questions will be addressed by developing simulator scenarios that demand transfer of control. We will then expose drivers to these scenarios with interfaces and control algorithms designed to smooth the transfer of control. These interfaces and algorithms will be designed to signal the authority ceded to the automation, the safe operational envelope of the automation relative to the current driving situation, and the current state of the sensors and algorithms relative to their control limits. The benefits of these designs will be measured in terms of the smooth and timely transfer of control. Smooth control will be measured in terms of response time of the driver relative to the onset of the event and the proximity to critical safety boundaries, such as time to line crossing and time to collision with the vehicle ahead. Smooth transfer of control will also be measured in terms of the subjective response of the driver, particularly the drivers' awareness of the automation state and trust in the automation.

Risk, Autonomy, and Software Lifecycles in Coordinated Synthetic Driving: This work draws on lessons learned from the aeronautics community on the risks of autonomy and from research on building teamwork between people and autonomous technology (e.g., bumpless transfers of control). Increasingly autonomous vehicles are software intensive systems, and software intensive systems involve a set of lifecycle issues (e.g., the continuing sequence of software upgrades to resolve bugs, upgrade functionality, and maintain security). How these software lifecycle issues are managed can have a large effect on the risk of loss of control events for autonomous capabilities.

Here we explore how to assess the risk of autonomy. The approach is to develop a risk analysis method for the potential for loss of control depending on the engineering pedigree of the autonomous capability/vehicle and the consequences of loss of control. The goal is to enable near real time calculation of a maximum *safe operational envelope* (SOE) based on a combination of the risk analysis and real time data about environmental conditions and human/vehicular activity nearby. The work to date has focused on software life cycle issues and on scenarios that challenge the robustness and resilience of the responsible human driver/ADS. This work includes a computational model of driver response to the vehicle behavior so that changes in the operational envelope can be related to safety benefits of autonomous systems.

Plans for next reporting period: We have two experiments we plan to conduct next year that will refine the model of driver-automation interaction and assess performance in response to critical pre-crash safety events. Specifically, we will now assume a much higher level of automation where the driver actually relinquishes full control to the ADS. The question we will address in the first experiment is how long before a driver takes over manual control must he or she be alerted in order to remain as safe when taking over manual control as he or she would when in full manual mode. The ideal is often referred to as a bump-less transfer of control. In the second experiment, we will provide the driver with two alerts, an initial alert letting the driver know that he or she will need to take over control in, say, a minute, and the subsequent one indicating that there the driver has, say, 10 seconds before control will revert to manual mode. These simulated driving situations, where transfers of control take place between the responsible human driver and the ADS, are being captured on the full scope simulator. When these videos are available, pilot testing of the experimental task will begin. Based on the pilot data, the method and stimuli will be modified for additional data collection.

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

Products

Refereed Journal Publications:

Taylor, T., Roman, L., McFeaters, K., Romoser, M., Borowsky, A., Merritt, D.J., Pollatsek, A., Lee, J.D. and Fisher, D.L. (submitted). Cell phone conversations impede latent hazard anticipation while driving, with partial compensation by self-regulation in more complex driving scenarios. *Human Factors*.

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

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

Divekar, G., Pradhan, A. K., Masserang, K. M., Pollatsek, A. and Fisher, D. L. (in press). A simulator evaluation of the effects of attention maintenance training (FOCAL) on glance distributions of younger novice drivers. *Transportation Research F*.

Durbin, D.R., McGehee, D.V., Fisher, D.L. and McCartt. (2014). Special considerations in distracted driving with teens. *The Annals of Advances in Automotive Medicine*, *58*, 69-83.

Lee, J. (2014). Dynamics of Driver Distraction: The process of engaging and disengaging. *The Annals of Advances in Automotive Medicine*, 58, pp. 24–32.

Liang, Y., and J. D. Lee. (2014). A hybrid Bayesian Network approach to detect driver cognitive distraction. *Transportation Research Part C: Emerging Technologies*, *38*, Jan. 2014, pp. 146–155.

Refereed Conference Proceedings:

Borowsky, A., Horrey, W., Liang, Y., Simmons, S., Garabet, A. and Fisher, D. L. (accepted). The role of working memory in driving related hazard anticipation. *Proceedings of the Human Factors and Ergonomics 2014 International Annual Meeting*, Chicago.

Yamani, Y., Samuel, S., & Fisher, D.L. (accepted). Simulator evaluation of an integrated road safety training program. *In Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, Chicago.

Zafian, T. M., Samuel, S., Borowsky, A. and Fisher, D. L. (January 2014). Can young drivers be trained to better anticipate hazards in complex driving scenarios? A driving simulator study. *Proceedin of the Transportation Research Board 93rd Annual Meeting 2013*, Washington, D.C.

Mehranian, H., Fisher, D. L., and Pollatsek, A. P. (January 2014). Novice and Experienced Drivers - Evaluation of Hazard Anticipation, Hazard Mitigation and Attention Maintenance Skills in Complex Driving Scenarios. Proceedings of the Transportation Research Board 93rd Annual Meeting 2013, Washington, D.C.

Samuel, S., Borowsky, A., & Fisher, D. L. (January 2014). Text Messaging While Driving: User Experience and Interface Type. *Proceedings of the Transportation Research Board 93rd Annual Meeting 2013,* Washington, D.C.

Hamid, M., Samuel, S., Borowsky, A., & Fisher, D. L. (January 2014). Evaluation of Effect of Total Awake Time on Driving Performance Skills: Hazard Anticipation and Hazard Mitigation-Simulator Study. *Proceedings of the Transportation Research Board 93rd Annual Meeting 2014,* Washington, D.C.

Muttart, J. W., Fisher, D. L., and Pollatsek, A. P. (January 2014). Comparison of Anticipatory Glancing and Risk Mitigation of Novice Drivers and Exemplary Drivers When Approaching Intersections in a Driving Simulator. *Proceedings of the Transportation Research Board 93rd Annual Meeting 2013,* Washington, D.C.

Collaborations

NCA&T is getting ready to start simulating some of the most important machine learning techniques for driver distraction detection, such as SVM and DBN. More extensive simulations will be performed when they have our driving simulator and use it to obtain experimental data. Furthermore, NCA&T has begun collaborating with the University of Massachusetts regarding driver distraction and related scenario. Driver distraction by in-vehicle devices such as navigation systems and analyzing the experiments results is the main focus of our collaboration. In addition to the above accomplishments, weekly presentations on the projects are being conducted to seek and share advice from other graduate students and faculty members.

Collaborations were also established between UMass Amherst and investigators in computer science at UMass Amherst working on semi-autonomous vehicles and transfer of control (they have partnered on an NSF grant that was recently awarded).

Impact

Research on the driving simulator at UMass Amherst has led to additions to the Manual on Uniform Traffic Control Devices (MUTCD), directly or indirectly (flashing yellow arrow; advanced yield markings). We expect that this research will impact the NHTSA guidelines for the performance measures used to evaluate the safety of in-vehicle devices and future guidelines that might apply to transfer of control with 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)

Accomplishments

Progress toward stated objectives and goals: The goal of project 4 is to use Bio-Injury data from given crash scenarios to suggest evasive action / driver position best suited to reduce injury. This period of performance picks up following the selection of the crash scenarios and the initial definitions of variables for data mining of the National Automotive Sampling System – Crashworthiness Data System (NASS-CDS). To review, the crash scenarios that had been selected included the following:

Scenario 1: Lead vehicle stopped

Vehicle is going straight in an urban (may also be rural) area, in daylight, under clear weather conditions, at an intersection-related location with a posted speed limit of 35 mph; and closes in on a stopped lead vehicle. Speeding and inattention are important factors.

Scenario 2: Vehicle turning at a non-signalized junction

Vehicle stops at a stop sign in a rural area, in daylight, under clear weather conditions, at an intersection with a posted speed limit of 35 mph; and proceeds to turn left against lateral crossing traffic. Obscured vision and inattention are important factors.

Scenario 3: Vehicle changes lanes

Vehicle is changing lanes in an urban area, in daylight, under clear weather conditions, at a non-junction with a posted speed limit of 55 mph or more; and then encroaches into another vehicle traveling in the same direction. High-speed roads and non-junction areas are more common in the crash data. Inattention is an important factor.

The variables used to mine the NASS-CDS database were as follows –

1. NASS CDS Data from years: 1998-2011
2. Vehicle Model Years: 1998 onwards [frontal airbags standard]
3. Occupant Age: 16 years and above
4. Sex: Male & Female; excluding pregnant occupants
5. Occupants: All Occupants & Drivers only (independent searches)

Major findings to date:

Resulting Database

a. 52% Male; 48% Female
b. 74% Driver; 26% All Other Occupants
c. Belt-use rate: 67% (M = 63%, F = 72%)

Body Region with greatest risk of serious injury changes with each scenario

a. Scenario 1 – Lead vehicle stopped
    i. Most serious injuries: spine & extremities
b. Scenario 2 – Turning at non-signaled junction
    ii. Most serious injuries: thorax
c. Scenario 3 – Vehicle changing lanes
    iii. Most serious injuries: head & face

It was extremely interesting to find that each scenario resulted in a different body region being at the highest risk for serious injury. It is important to note that even though all have differing regions of concern, none of the scenarios had larger than a 2% risk of serious injury. These findings have led us to look at different injury scales moving forward, as AIS is threat to life, but is not useful in tracking debilitating injuries that would result in higher cost to the occupant and society.

- CIREN – (Crash Injury Research & Engineering Network): We have applied for full access to the CIREN files through NHTSA, which include radiology images and reports. We hope to have this goal accomplished by December 2014.

Training or professional development: We have introduced three students (Tim Gocha, Tanisha Kashikar & Lauren Eicharn) to database mining and statistical analysis. This project has allowed us to expand our research center into the realm of data mining. This is proving to be useful on other ongoing projects in the center as well.

Dissemination of Results: The NASS-CDS results are currently being written into a Journal Article to be published in the Annals of Biomedical Engineering

Plans for next reporting period: CIREN findings will be analyzed and reported

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

Products
Publications: The NASS-CDS results are currently being written into a Journal Article to be published in the Annals of Biomedical Engineering

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

Society beyond science and technology: 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)

Accomplishments
Progress toward stated objectives and goals: The primary goal for Year 1, Project 5 was to develop simulation models for vehicle to pedestrian/cyclist pre-crash interval.

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

Activity 1: Create a driving simulation model of a pedestrian forward collision imminent braking (CIB) system using actual mannequin-based CIB testing data. A summary of these activities are as follows:

a. Since no one has provided pedestrian CIB models for public research, we try to treat the CIB system as a black box and develop a method and process to model a pedestrian CIB system based on vehicle pedestrian CIB test data. This method can be used to develop pedestrian CIB braking models for different vehicles.
b. Use this method to identify the set of data essential for developing a pedestrian CIB model.
c. Use the proposed pedestrian CIB model in a driving simulator environment to evaluate a realistic pedestrian CIB performance.
d. Use the pedestrian CIB model to evaluate the improvement of CIB operations in a V2V communication enabled environment.

This research is conducted in two phases, the first phase is to use the PreScan vehicle simulator provided by TASS International to create the pedestrian CIB model. The model describes the CIB performance based on the vehicle speed, pedestrian speeds, pedestrian sizes, the pedestrian motion direction relative to the vehicle motions, and lighting conditions. The work in the first phase has been completed.

Activity 2: Integrate the active safety sensing information in V2V study. Considering the great effort to enforce drivers to wear seatbelts, making pedestrians wear devices to support P2V is not only a technology issue but also a social issue. Our idea is to link V2V and CIB capabilities together and let a pedestrian CIB system tell other vehicles the presence of pedestrians. If a vehicle can exchange the pedestrian sensing information in real-time, the vehicle can get potential pedestrian crash information before itself can sense the potential crash, and hence have more lead time to respond to a potential crash and to improve safety. Three students are working on this problem. One student has performed the exhaustive search of all scenarios (including pedestrian related scenarios) that can benefit from combined V2V and CIB. The second student is developing a V2V messaging protocol for transmitting CIB detected information of pedestrians and bicyclists as well as non-V2V equipped vehicles. The third student uses the results of the first two students to develop a simulation on PreScan. The pedestrian CIB model will be used for vehicles to detect pedestrians and broadcast to other vehicles in V2V-CIB 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 studies. The device has been designed and successfully tested. TASI 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 CIB technologies to mitigate them.

Major activities, including milestones and dates: The first phase of Activity 1 has been completed. The second phase for activity 1 is to transfer the pedestrian CIB model generated from PreScan environment to the Realtime Technology driving simulator. A Realtime Technology desk driving simulator has been purchased and set up at IUPUI. Activity 2,3 and 4 are ongoing.

Major findings or results:
Activity 1: A PreScan model of a pedestrian CIB system has been developed.
Activity 2: The scenarios that can benefit pedestrians and non-V2V equipped vehicles are searched exhaustively. The topologically equivalent scenarios are categorized. The representative scenarios are being identified. This work is almost completed. The development of a V2V messaging protocol for transmitting CIB detected information of pedestrian as well as non-V2V equipped vehicles is half way done.
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

Dissemination of results: 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.

Plans for next reporting period: During the second year, UMASS plans on comparing in the driving simulator V2B collision warning systems with alternative roadway treatments (e.g., Dutch junction) in order to determine which, or both, function better than the current system.

Activity 1: IUPUI will work on the second phase to transfer the pedestrian CIB model generated from PreScan environment to the Realtime Technology driving simulator. Activity 2: A communication protocol for the exchange of CIB pedestrian sensing information will be defined by IUPUI.
Activity 3: Dr. O'Connor will continue to find collaboration partners to disseminate the Alcohol control device in the alcohol related transpotation study.
Activity 4: David Good and his graduate student Brandon Taylor are nearing completion of linking ACS with our police crash reports.

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

<u>Products</u>

***Refereed Journal Publications*:**

Gómez, R., Samuel, S., Romoser, M. R. E., Knodler, M.A., Collura, J., & Fisher, D.L. (accepted). "Mitigation of Pedestrian-Vehicle Conflicts at Stop-Controlled T-Intersections." *Transportation Research Record*.

Samuel, S., Romoser, M. R. E., Roman, L. G., Hamid, M., Gómez, R., Collura, J., Knodler, M. & Fisher, D. L. (in press). "Effects of advanced yield markings and symbolic signs on vehicle-pedestrian conflicts: a field evaluation." *Transportation Research Record*.

Fisher, D.L. and Strayer, D. L. (2014). "Modelling situation awareness and crash risk." *The Annals of Advances in Automotive Medicine*, *58*, 33-39.

Refereed Conference Proceedings

Gómez, R., Samuel, S., Romoser, M. R. E., Knodler, M. A., Collura, J., & Fisher, D. L. (January 2014). Mitigation of Pedestrian-Vehicle Conflicts at Stop-Controlled T-Intersections. *Proceedings of the Transportation Research Board 93rd Annual Meeting 2013*, Washington, D.C.

Bo Tang, Stanley Chien, and Yaobin Chen, "Obtain a Simulation Model of a Pedestrian Collision Imminent Braking System Based on the Vehicle Testing Data," *17th International IEEE Conference on Intelligent Transportation Systems* in Qingdao China on Oct 9, 2014.

Mingxin Liu, Stanley Chien, Yaobin Chen, "Improve Road Safety Using Combined V2V and Pre-Collision Systems," Abstract submitted to *The 24th International Technical Conference on the Enhanced Safety of Vehicles (2015 ESV).*

<u>Collaborations</u>

In-kind Support TASS International is 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 CIB data collection.

<u>Impact</u>

On the development of the discipline(s): The integrated V2V and CIB sensing enables the transmission of the detected pedestrians and cyclists information to other vehicles that potentially make the other vehicle get information early enough to avoid the pedestrian crashes. The cost for this improved safety for vehicles is low.

On the base of knowledge, theory, or methods: The pedestrian CIB modeling activity provides a pedestrian collision imminent braking model for real vehicles. This simulation model provides a realistic reference for evaluating the safety improvement for V2V related pedestrian safety studies.

On the development of transportation workforce development: Three 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 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.

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)

Accomplishments
Policy Analytics Research Project: This project was designed to understand how safety, crashes, and autonomous vehicles (also known as intelligent vehicles and smart cars) are discussed in the policy realm and what this tells us about the development of the technology, regulatory discussions, and barriers to the adoption of the technology. The data and methodology for this project employs Big Data Analytics, specifically using corpus and computational linguistics on large policy data collections.

For this particular project, one of the primary interests is in autonomous vehicle (i.e., intelligent vehicle and smart car) technology. The first investigative task was identifying the ways that this technology is talked about in the corpus. Using the initial empirical results, the research team is continuing to develop their research questions and analyze the data. For their initial paper, the research team is focused on how safety is discussed. There is empirical evidence indicating that there has been a shift from a human-based safety regime to one based on technologies. There are two possible hypotheses as to the reason for this. The first is that the limits of human-based safety regulations and programs have been reached. That is, programs and policies aimed at influencing human behavior to comply with safety regulations have done as much as they can. For instance, seat belt usage is now at approximately 87% (NHTSA, 2013[1]). Getting the additional 13% of drivers to use their seatbelts will require more than continuing with the current programs and policies since drivers who still refuse to use their seatbelts need other incentives. This may be technology-based. The second hypothesis is that the advances in technologies have made technology-based safety much more possible. The research is still being done to determine which of these hypotheses is correct. The results will be presented at a workshop/seminar for engineers and policymakers to be held in January 2015.

[1] USDOT NHTSA's National Center for Statistics and Analysis, 2013, Seat Belt Use in 2013 - Use in States and Territories, last accessed October 25, 2014, at http://www-nrd.nhtsa.dot.gov/Pubs/812030.pdf.

Safety Divide Research Project: A second research project looks at the socio-economic implications of access to safety technology and specifically whether there is a difference in who has access to safety. The data on the safety features available for each make and model of vehicles (23,000 plus) has now been collected by Beth-Anne. The next step is to decipher the Ohio Department of Transportation vehicle registrations. This will then be combined with census-level data at the 1000-person level. This will allow the researchers (Beth-Anne Schuelke-Leech and Matt Roberts) to look at patterns of access to newer vehicles, more fuel efficient vehicles, and safer vehicles to determine if there are systemic differences in the access to safety features. The researchers hypothesize that there is this systemic difference, which they are referring to as the *safety divide*. This research will also lead to research looking at the correlations between safety and fuel efficiency, as well as potential disparities in access to fuel efficiency technologies.

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

Products

Nothing to report.

Collaborations

The research team consists of Dr. Beth-Anne Schuelke-Leech, an Assistant Professor at the John Glenn School of Public Affairs and three visiting scholars at OSU: Dr. Betsy Barry (PhD Computational Linguistics), Dr. Clayton Darwin (PhD Computational Linguistics), and Suzanne Smith (JD). The visiting scholars are integral to this project because of the experience and methodological expertise that they have. The vast majority of regulatory and policy data are language-based, which makes it the appropriate methodology for this project.

Impact

Nothing to report.

Changes or Problems

Nothing to report.

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

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

Accomplishments

Summary: In this project we undertake multiple ***Activities***, each concentrating on a different new technology that may have an effect in improving pre-crash safety.

Activity 1: *Communication Networks*

The major goal of our effort is to investigate communication paradigms to support Crash-Imminent Safety systems and develop new alternative communication methods to support such systems at high performance levels.

1) During this reporting period, we have identified cognitive radio systems as a promising paradigm to assist crash-imminent safety systems by increasing the available bandwidth to achieve high availability and low latency. A simulation study was conducted to assess the gains attainable through an appropriate cognitive radio network solution.

2) The specific objective of our study was to
   a. Demonstrate the performance gains attainable to operate in a cognitive radio network setting using the essential structures of 802.11p standard
   b. Identify the performance region of the 802.11p standard in the cognitive radio setting vis-à-vis theoretically achievable performance levels.

3) Our simulation studies have revealed the following:
   a. V2V safety communications via IEEE 802.11p MAC combined with cognitive radio in the TVWS spectrum performs much better than the pure 802.11p MAC used in DSRC spectrum. Hence, it is advantageous to use TVWS spectrum in V2V safety communications.

   b. However, IEEE 802.11p MAC's performance is significantly below the theoretically achievable limits. Cognitive radio capability must be incorporated to improve the performance of IEEE 802.11p MAC in Cognitive Vehicular Networks. Therefore, novel efficient spectrum management mechanisms and MAC protocols must be developed to adapt the communication to the cognitive environment.

Activity 2: *Security*
The major goal of our effort is to increase the security of V2V and V2I communication to support Crash-Imminent Safety systems.

During this reporting period we developed an encryption scheme, which combines an elegant key pre-distribution scheme with a somewhat homomorphic encrypting system (Boneh-Goh-Nissim) to provide muddled secure session keys that can be used for encrypting transferred data in case of sudden disappearance of the vehicle to infrastructure (V2I) service. To investigate the appropriateness of the suggested model, in-depth analysis in terms of OBU storage and time overhead was conducted and the analytical results show that our scenario is practical and fast for small network sizes and compromisation rates.

Activity 3: *Sensing*
Both car-internal (driver related) and car-external (environment related) sensing modalities are to be considered. In this year's effort, a low cost EEG sensor was tested in order to ascertain how useful its data might be for indicating a driver's intent to make a lane change. From a preliminary evaluation of the data based on driving simulator tests, records of eye gaze behavior are the most prominent indicators of lane change intent. The underlying EEG patterns are also available in an EEG record over a sufficient amount of time. In order to detect the lane change intent, a matched filter and a Naive Bayes Classifier were applied. The preliminary study of EEG in a driver-sensing suite did not seem to add valuable information, results from the classification methods did not show any decrease in classification error with EEG data being added to the information of vehicle position and velocity. Future experiments with a larger data set, direct comparison to existing eye-tracking methods, and better signal processing to reduce sensor noise are considered.

Dissemination: Conference papers are being prepared that outline our findings pertaining to this reporting period.

Plans for next reporting period:

1) Evaluate the performance of IEEE 802.11p MAC when neighboring heterogeneous secondary networks are taken into account, e.g., IEEE 802.22 and IEEE 802.11af networks.
2) Quantify the effect of vehicular communications on primary users.
3) To accommodate larger networks, one future extension would focus on how to have smaller Blom's matrices elements such that even when N and λ are big the computation can be conducted as fast as possible with a minimum storage overhead.

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

Products

Publications:

You Han, and Eylem Ekici, "Simulation Study of Vehicle-to-Vehicle Safety Communications in Cognitive Vehicular Networks," in preparation, 2014

Sarah Al-Shareeda and Fusun Ozguner, "Secure Pairwise Key Establishment in Vehicular Networks", The 3rd International Conference on Connected Vehicles & Expo (ICCVE 2014) Nov 2014, Vienna, Austria.

Danielle Fredette and Umit Ozguner, " EEG and Lane Change testing with a Driving Simulator," *CrIS Internal Report*, July, 2014.

Other:

Simulator developed to assess the performance of 802.11p protocol under the cognitive radio settings.

Collaborations

Nothing to report.

Impact

Development of the principle discipline: The effort during this reporting period has uncovered facts behind long-held believes about the use of 802.11p protocol as a very good, real-time communication alternative. Our simulation studies show that 802.11p's use in the DSRC band is very inefficient when compared to cognitive radio bands, such as TV White Space. Moreover, we also showed that 802.11p utilizes any band it operates in very poorly, leading to poor real-time performance, which is a must for safety applications. These pieces of new knowledge are poised to change the perception of 802.11p standards in the research and development community from an "adequate" alternative to a "quick-and-dirty" solution with very poor performance.

Based on these observations, we are motivated to continue our efforts to find new ways to utilize available bandwidth such that vehicular networks and associated safety applications can deliver the expected performance levels.

Changes or Problems

Nothing to report.