CrIS | Crash Imminent Safety UTC

Program Progress Performance Report

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

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CENTER FOR AUTOMOTIVE RESEARCH

Overview:

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

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

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

Our Center's Annual Meeting was held on September 22, 2017. During the meeting, progress in each project was outlined by a representative of that activity, as well as a summary of work done of the project period.

Center researchers attended and made presentations at numerous technical conferences including the International Conference on Cyber-Physical Systems, IEEE ITS Conference, and the Annual TRB meeting.

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

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

Weekly presentations on the projects are being conducted at NCAT to seek and share advice from graduate students and faculty members.

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

Education and Outreach—F. Ozguner

Primary Goal: To transfer the knowledge gained through CrIS research efforts to the next generation of ITS engineers and to develop policies related to autonomous vehicle technologies through activities focused on technology transfer.

Activity 1- *Graduate Student Exchange Program:* One of the UTC's graduate students will be joining Director Umit Ozguner at Nagoya University in Nagoya, Japan in October 2018 to collaborate on an autonomous vehicle project.

Facilities and Experiments—K. Redmill

- We are studying the implementation of autonomous and semi-autonomous vehicles within the driving simulator software environment.
- The UTC is working with other stakeholders to support the development of new automated and connected vehicle testing facilities at the Transportation Research Center (TRC) in East Liberty. OH.
- This UTC continues to prepare a three to four vehicle experiment to be run at TRC, involving cooperative planning and control for merge and weave maneuvers.

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

Major Goals - Year 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 worked towards the networking of driving simulators across the institutions in the CrIS UTC. A final report will demonstrate the contribution and impact, and will be submitted under the appropriate guidelines.

Products: We completed two additional undergraduate research theses. One was a follow-up to the series of studies on causes of road rage in drivers. In the newly-completed study, we investigated the effect of bumper stickers shown on other vehicles on driver aggression. The bumper stickers were chosen to address the question of whether the weaker effects seen with aggressive-content billboards in the previous study occurred because the aggressive content was not tied to a "person." Attaching bumper stickers to passing vehicles provided a means to personalize the aggressive content. Bumper stickers contained either nonaggressive content or aggressive content, or contained either in-group (e.g., university team name) or out-group (e.g., rival university team name) content. Surprisingly, no effect of bumper stickers was observed for any of the aggressive driving measures (speed, following distance, or lane-keeping). There was a slight gender effect, with males exhibiting somewhat faster speed and closer following distances.

A second thesis focused on the impact of aging and hearing impairment on driving. Previous work in this area had suggested an impact of hearing impairment on cognitive workload while driving, but all of the participants in these previous studies had been elderly, confounding the question of whether the effects were due to hearing impairment, to aging, or to both. Preliminary data indicated that there is a significant effect of aging on driver behavior, with participants showing reduced situational awareness of other items in the scenario. Additional data collection is underway.

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 continue 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: Nothing to report.

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 developed the multi-agent models of the driver and the vehicle that can be used to inform the design principles for safety-focused and optimized advanced driver assistance systems and autonomous vehicles. In the second 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. Final reports will be written and submitted accordingly.

Accomplishments

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

In one recent study, CrIS researchers made further progress on cooperative adaptive cruise control on highways, which requires the lead vehicle of a vehicle convoy to be capable of resisting disturbances outside the convoy. The study (Liu2017Synthesis) proposed a controller synthesis approach adopting behavior classification to improve the lead vehicle's ability to deal with outer disturbances. First, a behavior classifier was developed based on hidden Markov models to detect dangerous driver behaviors of surrounding traffic participants. The classification results with corresponding predicted trajectories were then imported to a model predictive controller for the lead vehicle. A behavior-guided cost function of the controller was carefully designed to react to behavior differences and to contribute to convoy string stability. The impact of the lead vehicle's state deviation on the convoy was studied based on leader-to-formation stability properties. Furthermore, a nonlinear bound was also given to state the performance of the proposed controller. Simulations of a cut-in scenario were conducted using the CarSim simulation environment to show the effectiveness of the proposed controller.

The study presented in (Liu2017Distributed), CrIS researchers at OSU worked on the safety and stability aspects of the convoy scenario, using disturbance models guided by the driver modeling work carried out in the earlier reporting periods of the center. This study added to control theoretic knowledge base by investigating the stabilization problem of a class of spatially decoupled systems by applying distributed model predictive control (DMPC) with switched cost functions. The proposed DMPC scheme switches the optimization index on a switching surface generated by control invariant sets. By applying the index-switching strategy, stability of the closed-loop system is ensured by the feasibility of a series of constrained optimal control problems. In a related publication (Liu2017Distributed), a more efficiency-focused approach was taken. Macroscopic traffic management and microscopic vehicle dynamics were considered to achieve efficiently cooperative highway driving. Critical traffic information beyond the scope of human perception was obtained from connected vehicles downstream to establish necessary traffic management mitigating congestion. In the developed framework, with back propagating traffic management advice, a connected vehicle having an adjustment intention exchanges control-oriented information with immediately connected neighbors to establish potential cooperation consensus, and to generate cooperative control actions.

In a collaborative publication co-authored by NCA&T PI Homaifar and OSU researcher Kurt (Ramyar2017), CrIS students developed a control approach for automated highway driving, which can learn from human driving data, and is applied to the longitudinal trajectory of an autonomous car. Naturalistic driving data was used as samples to train the model offline. Then, the model was used online to emulate what a human driver would do by computing acceleration. This reference acceleration was tracked by a predictive controller, which enforces a set of comfort and safety constraints before applying the final acceleration. The controller was designed to balance between maintaining vehicle safety and following the model's commands. Thus, the proposed controller can handle dynamic traffic situations while performing like a human driver. This approach was validated on two different scenarios using MATLAB simulations.

Further work in safety applications in a human-driver-aware setting were conducted at NCA&T, with the results presented in (Wang2017). In this study, a collision avoidance system for lane change events was proposed which plans the trajectory based on the level of danger. The danger level was computed by a fuzzy inference system developed with naturalistic driving data to better capture the real-world factors, which may cause an accident. In addition, a fault determination classifier was introduced in order to determine the responsible driver in a near crash event. This system was evaluated on simulated naturalistic near crash events and the results demonstrate good performance of the proposed 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 fourth year:

Liu, P., & Ozguner, U. (2017). Distributed Model Predictive Control of Spatially Decoupled Systems Using Switched Cost Functions. arXiv preprint arXiv:1606.02224.

Liu, P., Kurt, A., & Ozguner, U. (2017). Synthesis of a behavior-guided controller for lead vehicles in automated vehicle convoys. *Mechatronics*.

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, 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. M., Homaifar, A., Nahavandi, S., & Karimoddini, A. (2017, June). A collision avoidance system with fuzzy danger level detection. In *Intelligent Vehicles Symposium (IV), 2017 IEEE* (pp. 283-288). IEEE.

J. Jing, D. Filev, A. Kurt, E. Özatay, J. Michelini, Ü. Özgüner, “Vehicle speed prediction using a cooperative method of fuzzy Markov model and auto-regressive model”. In Intelligent Vehicles Symposium (IV), June 2017 IEEE (pp. 881-886). IEEE.

Collaborations

NCA&T and Ohio State worked together to develop a driver models for safety-critical traffic scenarios using driving data collected in Ohio State University, and samples from larger naturalistic driving studies. One joint paper, as an example of the results of this collaboration, was given above in the list of products.

Impact: Nothing to report.

Changes or Problems: Nothing to report

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

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

Major Goals - Year 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 situations where the human driver and ADS need to change the shared SOE. The 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.

***Results to date*:** The results have led to formulation of a new architecture for shared control in human-autonomy systems, with additional funding from 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 (SOE). Additional funding on this architecture for Human-Autonomy Teaming allows for joint work with Georgia Institute of Technology.
Based on this new architecture, NASA funded a follow on project to demonstrate how to carry out a Resiliency Trade Space Study to assess potential risks from deployments of autonomous capabilities. The project has developed a new method for risk analysis for deployments of autonomous capabilities. Final reports will be submitted accordingly.

<u>Refereed Journal Publications:</u>

Farjadian, A. B., Annaswamy, A. M., Woods, D. D. and Lavretsky, E. (2018). A Shared Pilot-Autopilot Control Architecture. *IEEE Transactions on Control Systems Technology*. Submitted.
Woods, D. D. (2018). The Theory of Graceful Extensibility. *Environment Systems and Decisions,* in

press.CrIS UTC PPPR, 04/30/2018

Refereed Conference Proceedings:

Farjadian, A. B., Annaswamy, A. M. and Woods, D. D. (2017). Bumpless Reengagement Using Shared Control between Human Pilot and Adaptive Autopilot. In Proceedings of the 20th World Congress The International Federation of Automatic Control (IFAC), Toulouse, France, July 9-14, 2017.

Other: Invite Talks/Addresses:

Woods, D. D. Invited Talk, "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

Woods, D. D. Invited speaker, "Transformative concepts in human-autonomy teaming: New roles, new risks, new opportunities." NextGen Flight Deck Symposium, NASA Langley Research Center, Hampton, VA, February 15-16, 2017.

Woods, D. D. Invited speaker, Expert Workshop on Control and Responsible Innovation in the Development of Autonomous Machines, Hastings Center, Garrison, NY, April 25-27, 2016.

Woods, D. D. Plenary Address, Autonomous capabilities: The future is already here & it's not as advertised. 19th International Symposium on Aviation Psychology (ISAP), May 10, 2017.

Other: Workshops:

Woods, D. D. Workshop on Autonomy, Complexity and Resilience. Human Factors and Systems Safety Thinking. EuroControl, Brussels Belgium, September 28, 2017. 120 participants

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: Phase II was continued with a goal of looking at the 3rd scenario and re-analyzing the 1st two scenarios using newly applied statistics. Due to this re-analysis, a brief re- cap of all findings is below.
Progress (Phase II): The Crash Injury Research & Engineering Network (CIREN), a database that focuses on the details of injuries of very specific crashes, was used over the past two years to analyze the scenarios. While CIREN is not statistically significant, it follows the occupants from the crash to the hospital and

includes accident experts' opinions on what each mechanism of injury was (i.e. steering wheel, intruding door, air bag, etc.). It is important to note that for a case to be considered for CIREN, an occupant in the vehicle must have sustained at least a serious injury according to the Abbreviated Injury Scale (AIS).

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

a. Lead vehicle stopped – 59 cases
b. Vehicle turning – 160 cases
c. Vehicle changes lanes – 37 cases

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

To date, 59 case studies involving *lead vehicle stopped* have been analyzed. The CIREN database revealed that the most common serious injuries (AIS 3+) occurred to the thorax, followed by the abdomen, and lower extremities. Of the AIS 3+ injuries to the three regions above, lower extremity injuries accounted for 51% of all of the injuries and almost all of the were only AIS 3. Truck under ride impacts and secondary impacts caused most of these severe injuries to the thorax, abdomen, and lower extremities, which could account for the difference in findings between the NASS-CDS (Phase I) and CIREN (Phase II) searches. The interior vehicle component that caused the most thoracic injuries was the steering wheel (sometimes through the airbag), suggesting that secondary impacts are causing these injuries. In these cases, 63% of occupants were wearing a seatbelt, and the frontal airbag deployed in 92% of cases. Frontal airbag availability on the case vehicle was an inclusion criterion for this study.

To date, 160 case studies involving a vehicle turning in front of a 2nd vehicle have been analyzed. The CIREN database revealed that the most common serious injuries occurred to the thorax, followed by the head, and abdominal regions. Of the AIS 3+ injuries to the three regions above, serious thoracic injuries account for 47% of the injuries, while 35% were to the head, followed by 18% to the abdomen. In these cases, 86% of occupants were wearing a seatbelt, but the side airbag deployed in 26% of cases. Many of the vehicles included in the study did not have a side airbag available and/or the available airbag did not deploy. The leading mechanism of injury for these regions was contact with the intruding door structure, followed by b-pillar contact, and contacting a vehicle component through airbags. Most of the severe injuries are happening in secondary impacts. For autonomous vehicle programming, we suggest investigating ways to prevent secondary impacts, optimally align energy absorbing vehicle structures to reduce impact forces experienced by the occupant, and reduce overcorrection by the driver following initial impacts.

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

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

Products: Nothing to report.

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

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

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

Changes/Problems: Nothing to report.

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

Major Goals - Year 4: The primary goal for Project 5 in Year 4 was to develop simulation models for vehicle to cyclist pre-crash interval. Final reports will be submitted accordingly.

Accomplishments: TASI at IUPUI continues working on several 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 and cyclist forward autonomous emergency braking (AEB). A mathematical model for guiding the design of the pedestrian AEB based on the pedestrian AEB performance testing data of a commercially available vehicle was developed. The results were published. A Petri net model for the bicyclist AEB performance testing data of a commercially available vehicle is being developed.

Activity 2. Integrate the active safety sensing information in V2V study. Our idea is to link V2V and AEB capabilities together and let a pedestrian/cyclist AEB system tell other vehicles the presence of pedestrian/cyclists. If a vehicle can exchange the object sensing information in real-time, the vehicle can get potential pedestrian/cyclist crash information before itself can sense the cyclist crash, and hence, has more lead time to respond to a potential crash and to improve safety. Four graduate students have continue been working on this problem since year 3. The communication overload issues were studied and a proposed algorithm for solving these problems was developed and published. If several vehicles detect a number of pedestrians/bicyclists and broadcast the information, there should be a method for the message-receiving vehicle to map several messages to each individual pedestrian/bicyclist. A hierarchical algorithm for message object mapping was studied and a proposed algorithm for solving these problems was developed and published.

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 was published in 2017 Fast Zero conference in September 2017.

Activity 4. Build TASI 110-car ND database for online cloud storage and access. The intrinsic motion profile and road profile were extracted. Algorithms for detecting road departure, surrounding vehicles, pedestrians, bicyclists, etc. were developed. Video data mining was studied for surrounding vehicle detection and real time TTC computation, walking pedestrian detection from motion trajectories.

Activity 5. Address the following questions. What are the most important vulnerable road user crashes to mitigate? To what extent can these crashes be mitigated by AV technology? Is there sufficient evidence to suggest that vulnerable road user's technologies should be mandatory through, for example, FMVSS?

Activity 6. Naturalist bicyclist data collection and vehicle-bicyclist interaction behavior analysis.

Major findings or results:

Activity 1. A PreScan model of a Pedestrian/cyclist AEB system has been developed. The model uses the PreScan vehicle simulator provided by TASS International. The model describes the AEB performance based on the vehicle speed, pedestrian speeds, pedestrian sizes, the pedestrian motion direction relative to the vehicle motions, and lighting conditions. The goal of Activity 1 has been reached. A mathematical model for guiding the design of the pedestrian AEB based on the pedestrian AEB performance testing data of a commercially available vehicle was developed and published. A pedestrian AEB model was developed based on hundreds of pedestrian AEB system tests conducted by TASI from another research project funded by our industry partner. A Petri net cyclist AEB model is currently being developed based on hundreds of cyclist AEB system tests. One paper was published and another is in preparation.

Activity 2. Develop sensor fusion methods to process the pedestrian information obtained from the sensors on multiple vehicles. Since many vehicles can potentially detect multiple pedestrians/bicyclists the same time, they all may broadcast the related information in the V2V network. This has a potential causing communication network overload. To reduce the amount communication and computation work, message cascading and filtering algorithms were developed. The communication overload issues were studied and a proposed algorithm for solving these problems was developed. One conference paper was published.

Another problem is that when multiple vehicles detect several pedestrians/bicyclists in the same area at time many messages can be broadcast. Messages from different vehicles can indicate the same pedestrian/bicyclist. Since sensors have errors, one issue is how to find if different messages refer to the same or different pedestrians/bicyclists. A hierarchical algorithm for message object mapping was studied and a proposed algorithm for solving these problems was developed. One paper was published.

During the study of this topic, the idea was communicated with car manufactures. There is not a technical issue to send the message describing the detected objects. However, a major concern from car manufactures is what if the information is not accurate. This voluntary information may cause trouble to the sender. The other concern is the receiver uses the information incorrectly.

Activity 3. A driving simulation program based on the algorithm developed was implemented on a driving simulation to demonstrate the auto pullover. A manual input was used to mimic the trigger from the heart defibrillator. A paper was published in 2017 Fast Zero conference in September 2017.

Activity 4. Build TASI 110-car ND database for online cloud storage and access. The intrinsic motion profile and road profile were extracted. Algorithms for detecting road departure, surrounding vehicles, pedestrians, bicyclists, etc. were developed. Video data mining was studied for surrounding vehicle detection and real time TTC computation, walking pedestrian detection from motion trajectories. Investigation of road appearances under various weather and illumination conditions was carried out through video data mining for road edge detection. Three papers were presented at international conferences of pattern recognition and IEEE IV.

Activity 5. Approach integrates test track crash information with a nationally representative crash data to determine how crash outcomes would change with AEB system. The conclusions are that even if AEB systems are completely ineffective in crashes involving the vehicle turning, they still provide important benefits in the most serious crash scenarios: potentially saving about a third of pedestrian fatalities, and a third of the crashes with a social cost savings of approximately $900 per deployed system. The policy related study also found that (1) Bicyclists have a wider variety of important behaviors than pedestrians. (2) Bicyclists speed is another potential source for harm. (3) Older cyclists are more prone to serious injury (frailty). (4) The most serious crash configuration is the cyclist being struck from behind. (5) We predict bicyclist injuries and injury prevention by assuming that they are related to relative speed between vehicle and bicyclist. The conclusion is that even under the best case with cyclist speed at AEB system “sweet spot” of 10mph, AEB offers little life-saving benefit for any but the oldest bicyclists. Papers were presented at several conferences that have disseminated our work to a broader group of policy analysts and decision makers: Society for Risk Analysis, Society for Benefit Cost Analysis as well as the IEEE Intelligent Transportation Society conferences.

Activity 6. Naturalist bicyclist data collection and vehicle-bicyclist interaction behavior analysis. Our study on bicyclist behavior has several dimensions, some stemming from vehicle video data and some in developing systems to follow the bicyclist. Key goals in this analysis have been to develop systems that, like naturalistic driving data, can lead to realistic behavior, different from what would be collected in simulators. This requires a system that is light and unobtrusive, and requires no cyclist intervention to turn on or off, and can be deployed for long periods of time. Two competing systems were developed, each with strengths and limitations. One system used depth-from-defocus as an inexpensive way to range objects in the cyclist's field of view. The second uses a simpler and less power hungry set of cameras and other sensors but does not include this ranging ability. 16 subjects were enrolled with data collected for a month each of riding behavior. This data is currently being analyzed.

Products:
Publications, conference, papers, and presentations:

1. Alberto López, Stanley Chien, Lingxi Li, Qiang Yi, Yaobin Chen, Rini Sherony, "Certainty and Critical Speed for Decision Making in Tests of Pedestrian Automatic Emergency Braking Systems," *IEEE Transactions on Intelligent Transportation Systems,* Volume: 18, Issue: 6, June 2017, **Pages:** 1358 - 1370.
2. Wasif Javaid; Yaobin Chen; Stanley Chien, Design and Implementation of Vehicle Automatic Emergency Pull Over Strategy Using Active Safety Systems on a Driving Simulator, Fourth International Symposium on Future Active Safety Technology Towards Zero Traffic Accidents (Fast-zero), Nara, Japan, September, 18-22, 2017.
3. Qiang Yi, Stanley Chien, Li Fu, Lingxi Li, and Yaobin Chen, Rini Sherony, "Clothing color of surrogate bicyclist for pre-collision system evaluation, 2017 IEEE IV conference, June, 2017 California.
4. 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." 25th International Technical Conference on Enhanced Safety of Vehicles (ESV) June 5-8, 2017, Detroit, USA.
5. Shalabh Rakesh Bhatnagar, Stanley Chien, Yaobin Chen, "Effect of delay in V2V-AEB system and ways to handle it," 25th International Technical Conference on Enhanced Safety of Vehicles (ESV) June 5-8, 2017, Detroit, USA.
6. M. Kilicarslan, J. Y. Zheng, Direct vehicle collision detection from motion in driving video, IEEE Symposium on Intelligent Vehicles, 2017, 1558-1564.6.
7. M. Kilicarslan, J. Y. Zheng, Bridge motion to collision alarming using driving video, 23th International Conference on Pattern Recognition, 1870-1875, 2016.
8. M. Kilicarslan, J. Y. Zheng, K. Raptis, Pedestrian detection from motion, 23th International Conference on Pattern Recognition, 1857-1863, 2016.
9. D. Good, S. Chien, L. Li, K. Krutilla and Y. Chen, Preliminary benefit analysis for pedestrian crash imminent braking systems. 18 th International Conference on Intelligent Transportation Systems (ITSC) 2015. 1123-1128
10. D. Good, K. Krutilla, S. Chien, L. Li and Y. Chen, Analysis of Potential Co-Benefits for Bicyclist Crash Imminent Braking Systems, 20 th International Conference on Intelligent Transportation Systems, forthcoming, 2017

Collaborations: TASS International has been providing the PreScan vehicle simulation software to IUPUI for the development of the simulation model and pedestrian AEB and V2V simulation. Toyota Collaborative Safety Research Center sponsored bicyclist AEB research provided the empirical testing data needed for this UTC project.

Facilities: Faurecia Emission Control Technologies, USA, LLC is providing vehicle test track to IUPUI for pedestrian/bicyclist AEB 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 only on the software side. Since this technology relies on the vehicles to share the information of their sensed objects, various checks need to be implemented for the correctness of the information and rules need to be set for the information to be broadcast for avoiding communication jam.

The development of the automatic pullover algorithm for drivers who lost ability of driving can greatly reduce the vehicle collision caused by driver's medical conditions (e.g. heart defibrillation). This auto pullover technology relies on all advanced vehicle active safety features and the establishment of the communication between the medical condition sensors and the vehicle.

The video data mining in this year covers the investigation of road appearances under different weather and illumination conditions for the development of road edge detection algorithms. The big data of the road profiles are extracted from naturalistic driving videos and their weather and illumination related features are collected for analysis. The K-means algorithm is used to cluster the similar types of samples in the feature space such that their common property distributions in the same clusters can be used to guide the design of road edge detection algorithms. The obtained weather and illumination clusters are compared to our human tagged categories of weathers, and the results are used to recognize or classify video frames from driving through different road and time.

On the development of transportation workforce development:

Four 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 (Jie) played a major role in the algorithm development. Four undergraduate students participated in the senior capstone design projects to develop a hardware of a road departure simulator based on sampling videos. Three master students in the Department of Computer Science have been involved in the driving video database development and server side programming. Fifteen master students in the multimedia course of Computer science department participated in a term project to evaluate the performance and accuracy of our pedestrian detection. Three graduate students and two undergraduate students have selected driving video processing as their independent study course. Five undergraduate students have also participated in the term projects to numerically evaluate the algorithm and method based on sampling videos. One undergraduate and one master have become co-authors of the international conferences with a PhD student and advisor. Two PhD students have devoted to the data mining of road appearances in driving video and developed initial methodology to detect road edges under various weather and illumination conditions. The driving video database allows uploading video from external users, which serves as a platform of data collection and analysis.

Over the course of the project, six graduate students in the School of Public Affair and Environment have been involved with the various projects. These were at a rate of typically one or two students over the course of the year. A student will be retained as projects wind down over the course of the next year.

Changes or Problems: Nothing to report.

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

Changes or Problems: This investigation has concluded.

Project 7. Technology and Enhancements to Improve Pre-Crash Safety
Investigators— Ü. Özgüner (OSU), lead; Chen (IUPUI); Coifman (OSU) Homaifar (NCA&T); Ekici (OSU); F. Özgüner (OSU); Redmill (OSU); Zheng(IUPUI); Koksal (OSU)

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

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

Accomplishments: 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:

1. S. Al-Shareeda and F. Özgüner, "Preserving location privacy using an anonymous authentication dynamic mixing crowd," in proceedings of the IEEE 19th International Conference on Intelligent Transportation Systems (ITSC2016), pp. 545-550, 2016.
2. Y. Feng, S. Al-Shareeda, C. Emre Koksal, and F. Özgüner, "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 collaboration with Prof. Can 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 to cater to the needs of both sensing and communication functions of vehicular networks.

Accomplishments: During this reporting period, we investigated the performance of a joint communication and radar system in the 79GHz band, where radar and communication functions are 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. To that end, we took a holistic approach and assessed the performance of our developed 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. DSRC band is necessary to serve as a control channel for successful facilitation of cooperative communication and sensing among vehicles
2. The high bandwidth made available for communication needs to be expanded to multi-hop cases, which is only possible through coordination among vehicles.

***Dissemination*:** Two journal papers summarizing our research outcomes have been published in IEEE Vehicular Technology Magazine and IEEE Transactions on Wireless Communications.

Products:

You Han, Eylem Ekici, Haris Kremo, Onur Altintas, Throughput-Efficient Channel Allocation Algorithms in Multi-Channel Cognitive Vehicular Networks, IEEE Transactions on Wireless Communications, vol. 16, no. 2, pp. 757-770, February 2017.

You Han, Eylem Ekici, Haris Kremo, Onur Altintas, Vehicular Networking in the TV White Space Band, vol. 16, no. 2, pp. 52-59, June 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. 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. It turns out that these dependencies can also emerge in seemingly free flow traffic. Specifically, when traveling next to a slow-moving lane some drivers will choose a free speed below the speed limit. This new-found regime will help advance our understanding of how congested traffic can really a mix of queued and non-queued traffic, and thus, having the potential to exhibit properties of both states.

Products:

Journal articles:

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

Ponnu, B., Coifman, B. "When Adjacent Lane Dependencies Dominate the Uncongested Regime of the Fundamental Relationship," *Transportation Research Part B*. Vol. 104, 2017, pp 602-615.

Conference papers:

Ponnu, B., Coifman, B., "Speed-Spacing Dependency on Relative Speed from the Adjacent Lane: Presenting New Insights for Car Following Models" *Proc. of the 96th Annual Meeting of the Transportation Research Board*, 2017. (peer reviewed).

Ponnu, B., Coifman, B. "When Adjacent Lane Dependencies Dominate the Uncongested Regime of the Fundamental Relationship- Abridged," [in review] *Proc. of the 97th Annual Meeting of the Transportation Research Board*, 2018. (peer reviewed).

Collaborations: NSF.

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.