SEMI-ANNUAL PERFORMANCE REPORT

OCTOBER 2020 TO MARCH 2021

SAPR #8

SAFE-D: SAFETY THROUGH DISRUPTION UNIVERSITY TRANSPORTATION CENTER

SAN DIEGO STATE UNIVERSITY

Texas A&M Transportation Institute

VIRGINIA TECH TRANSPORTATION INSTITUTE
VIRGINIA TECH

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Program Director Name, Title, and Contact Information	Dr. Zachary R. Doerzaph **zdoerzaph@vtti.vt.edu** (540) 231 – 1500
Name of Submitting Official	Eric Glenn Program Manager, Safe-D National UTC EGlenn@vtti.vt.edu (540) 231 – 1536
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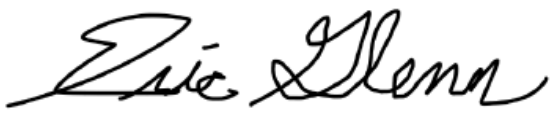
Signature of Submitting Official	

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Accomplishments

Major Goals of the Program

Fueled by the inevitable changes in our transportation system, the Safety through Disruption (Safe-D) National University Transportation Center (UTC) endeavors to maximize the potential safety benefits of disruptive technologies through targeted research that addresses the most pressing transportation safety questions. With the outstanding leadership of the Virginia Tech Transportation Institute (VTTI) and the Texas A&M Transportation Institute (TTI) in a mentoring collaboration with the new transportation research group at San Diego State University (SDSU), a Hispanic-Serving Institution known for educating the transportation workforce, our geographically balanced consortium encompasses the largest group of transportation safety researchers in the nation and provides unparalleled expertise, facilities, and resources to conduct impactful research toward our long-term vision. The Safe-D National UTC focuses its efforts in three key areas: (1) cutting-edge research conducted by leading transportation safety experts and their students; (2) education and workforce development (EWD) for programs of all levels, from grade school through college and extending to continuing education for professionals; and (3) fully supported technology transfer (T2), including practitioner training partnerships, social networking, commercialization, and intellectual property management. Furthermore, Safe-D met with the stakeholders to further strengthen our relationship with our industry partners and make suggested updates to our program. Our applications areas were updated to fit our goals and the growing change in transportation. Accessibility was added as an application bubble and the driver factors and interface bubble was updated to occupant factors and interfaces.

Figure 1 Updated Application Areas

Accomplishments During This Reporting Period

Project Awards and Activity

Safe-D did not solicit research proposals during this reporting period. However, Safe-D funded multiple directed projects along with some projects from the previous call for proposals. Directed projects were awarded by the Safe-

D team based on a high impact merit, opportunity to work with strong collaborators, and resource availability. Nearly all awards made during this reporting period received matching funding from industry sponsors meeting or exceeding the federal funding match requirement. Industry partners for projects from this round of awards include The Global Center for Automotive Performance Simulation, Commonwealth Cypher Initiative Cypher Security Research Collaboration, Ford, the Insurance Institute for Highway Safety, and the Virginia Department of Transportation.

At the end of this reporting period, the Safe-D National UTC had a project portfolio of more than $27.0 million, with over one-half of project funding sourced from non-federal matching funds. Safe-D projects are selected according to their focus on four Center theme areas: automated vehicles, connected vehicles, big data analytics, and transportation as a service. The coverage of Safe-D themes by project portfolio to-date is shown in Figure 2 (percentages are based on the number of projects reporting a focus in one or more Safe-D theme area(s), resulting in a total of over 100%).

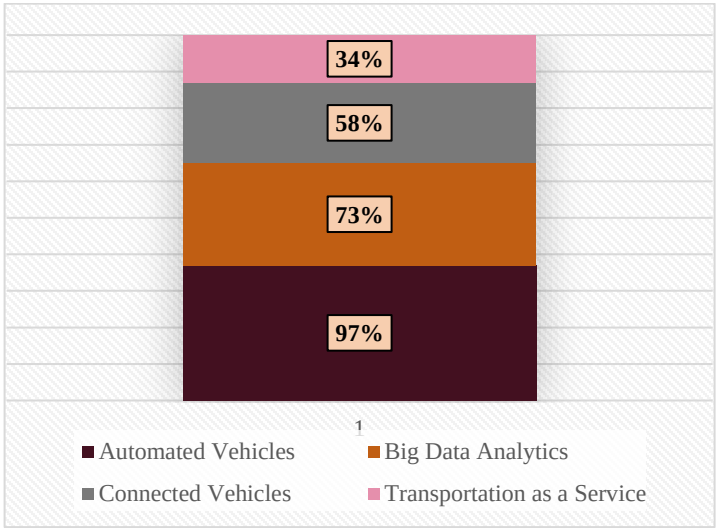

Figure 2. Portfolio of Safe-D Projects by Theme Area (total exceeds 100% due to projects covering multiple theme areas)

The Safe-D Leadership Team feels strongly that the projects awarded during this reporting period contribute to the overall Safe-D vision and mission. The Leadership Team is excited about the potential of these projects to maximize the safety of disruptive technologies as they are integrated into our transportation system. Safe-D research projects awarded during this reporting period, their respective theme(s), and short descriptions are reported below. A (*) denotes the lead institution.

Newly Awarded

Project 05-096: Curb Management Practices and Effectiveness in Improving Safety

Institution(s): TTI, VTTI; Award Round: Winter 2021; Theme Area(s): Automated Vehicles*

This project will address how vehicles in a multimodal environment are managed and prioritized at curb loading and unloading zones between different public and private vehicles and/or use cases. The research will analyze the effectiveness of curb management practices in improving safety through reduced collisions with pedestrians and other vehicles.

Project 05-098: Crashworthiness Compatibility Investigation of Autonomous Vehicles with Current Passenger Vehicles

Institution(s): TTI; Award Round: Winter 2021; Theme Area(s): Transportation as a Service, Automated Vehicles

This project will test and evaluate criteria to investigate crash compatibility between autonomous and human-driven vehicles, with consideration of different potential crash scenarios.

Project VTTI-00-033: Human Factors of Level 3 Automation: Surprise Event Response Evaluation

Institution(s): VTTI; Award Round: Winter 2021; Theme Area(s): Automated Vehicles

This project will be an extension of previous Ford and VTTI collaborations to assess drivers' responses during a surprise event. A test platform, based on a 2019 Ford Edge and built as part of a previous collaboration, will be used to effectively provide drivers with a level 3 automation driving experience on a real-freeway at highway speeds.

Project VTTI-00-036: Smart Work Zone System
Institution(s): VTTI; Award Round: Spring 2021; Theme Area(s): Automated Vehicles, Connected Vehicles*
In the previous Safe-D project 04-104, a prototype wearable Personal Protective Equipment vest was developed and was demonstrated to accurately localize, monitors, and predict potential collisions between work zone workers and passing motorists. The system also notifies workers when they are about to depart safe geo-fenced safe areas within work zones. The project will produce additional design iterations to simplify, ruggedize, and reduce per-unit costs to increase the likelihood of broader adoption. In addition, two new useful components were identified that would support a more effective deployment package. A base-station will be added that provides an edge computing environment for alert algorithm processing, consolidates communications of individual worker positions via a 4G link to a cloud computing environment, and can be coupled with a local roadside unit to support the broadcast of work zone information to connected vehicles. A smart cone device will be added that can help automatically define safe area boundaries and improve communications reliability between workers and the base station. The entire package is being developed to support a broader scale deployment of the technology with the Virginia Department of Transportation (VDOT).

Project VTTI-00-034: Sensor Degradation Detection Algorithm for Automated Driving Systems
Institution(s): VTTI; Award Round: Spring 2021; Theme Area(s): Automated Vehicles*
The project will develop a sensor degradation detection algorithm for Automated Driving Systems (ADSs). Sources of degraded sensor information include weather, cyberattacks (e.g., direct communication and passive false signage), and sensor malfunction. From the VTTI's Naturalistic Driving Database (NDD), 1,000 events related to sensor perception will be selected to establish baseline sensor performance. VTTI will then determine performance metrics using these events extracted from the NDD for comparison in simulation. A virtual framework will be used to test degraded sensor states and the response of the vehicle control systems to develop the detection algorithm. The framework will integrate the sensor models, environments, vehicle models, cyberattacks, and algorithms. Old Dominion University will develop the GPS model, which is a localization sensor, and collaborate with the Global Center for Automotive Performance Simulation (GCAPS) to develop the degradation detection algorithm. GCAPS will also create the virtual framework, develop the LiDAR and radar sensor models, and execute the simulations. The sensor degradation detection algorithm will aid ADS-equipped vehicles in decision-making by identifying degraded sensor performance.

Project TTI-Student-07: Assessment of Work Zone Pre-crash Scenarios Using Crowdsourced Data
Institution(s): TTI; Award Round: Spring 2021; Theme Area(s): Connected Vehicles, Automated Vehicles*
This project will identify unsafe driving events in work zones from videos collected by Nexar's front-facing dashboard camera (dashcam) and trajectory data. The results of this project could be used for developing ADSs and automated driver assistance systems (ADAS) to improve the safety in work zones.

Completed Projects

During this reporting period, research activities on the following projects were completed:[1]

- 04-098: Data Mining Twitter to Improve Automated Vehicle Safety
- 04-104: Development of a Connected Smart Vest for Improved Roadside Work Zone Safety
- 04-113: Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements
- 04-115: Reference Machine Vision for ADAS Functions
- SDSU-01-01: Prediction of Vehicle Trajectories at Intersections Using Inverse Reinforcement Learning
- VTTI-00-022: Automated Truck mounted Attenuator

As with the selection of Safe-D projects, Safe-D Final Research Reports undergo a rigorous, iterative peer-review process, including reviews by the Safe-D Leadership Team, Subject Matter Expert(s), and the Technical Editing

[1] The outputs of these projects are currently under final review and are expected to be published during the next reporting period, per the Safe-D data management plan (DMP) and grant requirements.

team at VTTI. The following projects were finalized during this reporting period and/or final research reports were published to the Safe-D website and distributed to repositories, as per grant requirements:

- 03-036: Modeling Driver Behavior During Automated Vehicle Platooning Failures
- 03-072: Preventing Crashes in Mixed Traffic with Automated and Human-Drive
- 03-073: Autonomous Emergency Navigation to a Safe Roadside Location
- 04-103: Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: A Naturalistic Approach - Phase II Analysis of the Naturalistic Driving Data
- 04-101: Safety Impact Evaluation of a Narrow-Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway
- VTTI-00-029: Real-world Use of Automated Driving Systems and Their Consequences
- TTI-01-01: Analysis of an Incentive-Based Smartphone App for Young Drivers

Safe-D Programming

As noted in the original proposal, Safe-D has commenced a number of programs targeting its Leadership, Education and Workforce Development, Technology Transfer, and Diversity initiatives. The following sections highlight major accomplishments under these directives.

Continuing Education/Professional Development

Safe-D continues to develop and implement many continuing education and professional development activities. All Safe-D researchers are encouraged to seek out opportunities in this area at the project level and to conduct these activities at the program level. Many of these activities are described in the Highlighted EWD & Other Outreach Activities and Outputs section; additional activities reported by research teams during this period are listed below:

- Safe-D project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) presented their research to the Town of Blacksburg Corridor Committee.
- Safe-D Project 05-109 (ENDEAVRide) presented their research results at the Transportation Research Board and Central Texas Council of Governments.
- Safe-D project VTTI-00-025 (Radar and LiDAR Fusion for Scaled Vehicle Sensing Test) research was used by a student for their Thesis Defense.

Professional Skills Training Series

The Safe-D Professional Development webinar series continued with a session titled *Tips for Virtual Interviews*, which was presented on December 14, 2020, to an audience of 18 graduate students. Presentations by Dr. Chrysler and Dr. Tooley included tips from human resources professionals concerning technology set-up, preparation, and conducting the interview.

Student Awards Program

Safe-D is proud of its students' accomplishments and continues to encourage students to seek opportunities, including the Eno Leadership Development Program, the Eisenhower Fellowship Program, and other student awards and leadership development opportunities that arise. The following is a selection of awards that our students have received during this reporting period.

Safe-D Student Named 2020 Outstanding Student of the Year

Safe-D selected Adam Novonty as the 2020 Outstanding Student of the Year Award (SOYA) for his many accomplishments working on various Safe-D projects. Adam was first author on a soon-to-be published paper titled "Concept Development of the Novel Pre Rear-End Positioning and Risk Extenuation System (PREPARES)." In 2019, his team won the international title with this project in the Collegiate Student Safety Technology Design Competition (SSTDC) of the Enhanced Safety of Vehicles (ESV) 26th International Technical Conference. More information on Adam's SOYA can be found here.

Additional Student Awards

During this reporting period many other Safe-D students also received awards for their exceptional efforts.

- Nicholas Britten received the Industrial and Systems Engineering Master's Student of the Year (Virginia Tech Grado Department of Industrial and Systems Engineering) and also joined Alpha Pi Mu (the Industrial Engineering Honor Society).

Educational Courses Taught and Students Supported

Safe-D researchers are actively engaged in teaching efforts at each of the consortium universities and in supporting students through the conduct of research activities. While formal metrics are reported annually in the Program Performance Indicators, the following is a description of the metrics for this reporting period regarding courses taught and student support provided through the Safe-D program. During this reporting period, researchers involved in Safe-D research projects taught 31 graduate and 24 undergraduate courses, reaching 407 graduate and 1,437 undergraduate students. Safe-D research projects supported 44 undergraduate- and graduate-level students during this reporting period. The breakdown of the students supported during this period are presented in Table 1.

Table 1. Description of Students Supported under Safe-D Research Activities

Academic Level	Total Number of Students Supported	Number of Underrepresented Students Identified
Undergraduate	10	3
Masters	17	2
PhD	31	10

Highlighted EWD & Other Outreach Activities

- Safe-D Project 03-036 (Modeling Driver Responses During Automated Vehicle Failures) researchers gave simulator tours to middle and high school students during Texas A&M's Aggieland Day.
- Safe-D project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety) researchers created a One Pager for Public Information Officers on social media guidelines for discussing automated vehicle incidents.
- Safe-D Project TTI-05-02 (Analysis of Advanced Driver-Assistance Systems in Police Vehicles) authors created STEM activities for undergraduate engineering honor students.
- Safe-D TTI-05-01 Project (Connected Vehicle Data Safety Applications) authors presented at the Texas A&M Transportation Data Science Seminar Series and the internal 3M tech forum.
- Safe-D Project 05-109 ENDEARide authors presented to doctors at Baylor Scott and White, the City of Nolnaville, and launched an event at Nolanville City Hall that reached around 100 practitioners.

Safe-D Webinars

Safe-D hosted its first webinar in January 2020. Since then, we have built a robust and dynamic archive of webinars attracting audiences from varying transportation disciplines. A list of all webinars can be found on the Safe-D site in the webinar archive tab. The average number of webinar attendees during this reporting period was 23. The average number of YouTube views for all Safe-D webinars during this reporting period was 28. Safe-D is working to increase these number by adding mailing list for researchers to sign up and receive notifications of new webinars.

Safe-D Upcoming Webinar Series

We expect the following webinars to be presented in the upcoming months.

Examining Seniors' Adaptation to Mixed Functions Automated Vehicles: Analysis of Naturalistic Driving Data

Safe-D is currently working with the authors of project 04-103 Examining Seniors' Adaptation to Mixed Functions Automated Vehicles: Analysis of Naturalistic Driving Data to provide a webinar scheduled for late May. The

webinar will be hosted by Dr. Jon Antin and Dan Liang. This projected investigated the that ways ADAS-equipped vehicles may influence seniors' driving performance both positively and negatively.

Developing of a Connected Smart Vest for Improved Roadside Work Zone Safety

Safe-D is currently working with the authors of project 04-104 Developing of a Connected Smart Vest for Improved Roadside Work Zone Safety to provide a webinar scheduled for July. The webinar will be hosted by Dr. Mike Mollenhauer and Dr. Nazila Roofigari-Esfahan. This projected examined the benefits of a smart vest that utilizes the previously developed Threat Detection Algorithm from Safe-D project 03-050 Design and Evaluation of a Connected Work Zone Hazard Detection and Communication System for Connected and Automated Vehicles (CAVs), to communicate workers' locations to passing connected/automated vehicles and proactively warn workers and passing motorists of potential collisions.

Data Mining Twitter to Improve Automated Vehicle Safety

Safe-D is currently working with the authors of project 04-098 Data Mining Twitter to Improve Automated Vehicle Safety to provide a webinar scheduled for June. The webinar will be hosted by Dr. Anthony McDonald. This projected investigated ways to understand the conversation about automated vehicles on Twitter through a network and natural language processing analysis with an emphasis on responses and changes of opinion surrounding automated vehicle crashes.

Safety Impact Evaluations of a Narrow-Automated Vehicle-Exclusive Reversible Lane on Existing Smart Freeway

Safe-D is currently working in combination with ITE San Diego on project 04-101 Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway to provide a webinar. A date has yet to be determined. The webinar will be hosted by Dr. Sahar Machiani and Dr. Arash Jahangiri. This projected conducted a series of research approaches, including a literature review, an automated vehicle (AV) manufacturers product review, expert interviews, a consumer questionnaire review, crash data analysis, and traffic simulation analysis to develop recommendations and guidelines usable for practitioners and professional organizations pertaining to AV development.

Safe-D Researcher Honors and Awards

During this reporting period, many Safe-D Faculty received awards for their exceptional efforts and research:

- Dr. Sahar Ghanipoor Machiani and Dr. Arash Jahangiri received the Western District ITE [Institute of Transportation Engineers] Transportation Achievement Award for Transportation Systems Management and Operations (TSMO).
- Dr. Nazilia Roofigari-Esfahan received the Research Excellence Award from the College of Architecture and Urban Studies.
- Dr. Maryam Zahabi, Texas A&M University Department of Industrial and Systems Engineering, received a National Science Foundation Faculty Early Career Development Program (NSF CAREER) award to study Adaptive Driver Assistance Systems and Personalized Training for Law Enforcement Officers, which builds upon her current Safe-D project. https://www.nsf.gov/awardsearch/showAward?AWD_ID=2041889&HistoricalAwards=false
- Dr. Susan Chrysler, Safe-D Associate Director at the Texas A&M Transportation Institute, received the Texas A&M University Board of Regents Fellow Service award " to recognize and honor service, extension and research professionals who have provided exemplary professional service to society that has created large and lasting benefits to Texas and beyond." https://tti.tamu.edu/news/ttis-bullard-and-chrysler-named-regents-fellows-for-transportation-research-service/

Dissemination of Results

Research Project Results

Research results from Safe-D projects continued to be finalized during this reporting period. Safe-D researchers have been submitting and publishing results of their projects in peer-reviewed journals and presenting results at conferences nationwide. The publications, presentations, theses and dissertations, websites, and more avenues of dissemination reported thus far by researchers are listed in the Outputs section of this report. Project teams have also actively disseminated the results of their research projects through outreach, EWD, and T2 events, including those listed in the Highlighted EWD & Other Outreach Activities section.

Plans for Next Reporting Period

Safe-D programming for the next reporting period has continued to be significantly impacted by COVID-19 as it was in the previous reporting period. Many EWD outreach activities and T2 demonstrations that were planned for this reporting period have either been cancelled or postponed or moved to virtual meetings making our goals in these areas difficult to achieve. The impacts of COVID-19 on Safe-D research are described in detail in the Impact of COVID-19 section of this report.

Participants and Collaborating Organizations

Partner Organizations

In addition to inter-consortium collaborations on Safe-D research projects, the Safe-D T2 Plan requires each new project team to be matched with a project champion from industry who will provide a built-in "customer" for the research, further aligning the project with industry needs. The domestic and international collaborations listed below highlight some of the reported collaborations during this period.

Domestic Collaborators

- Project TTI-Student-08 (Identifying Deviations from Normal Driving Behavior) members collaborated with Toyota Collaborative Safety Research Center and State Farm Insurance and the TTI Center for Transportation Safety contributed in-kind.
- Project 04-113 (Disruptive Technologies for Safety Analysis) researchers collaborated with VDOT for safety performance function development.
  Project 04-115 (Reference Machine Vision for ADAS Functions) researchers created a partnership with 3M to provide materials for testing and useful suggestions for the research.
- Texas A&M Engineering Extension Services assisted Project TTI-05-02 (Analysis of Advanced Driver-Assistance Systems in Police Vehicles) authors with recruiting police officers from state-wide police departments for the phase 1 experiment.
- Project VTTI-00-025 (Radar and LiDAR Fusion for Scaled Vehicle Sensing Test) researchers collaborated with Continental Automotive to receive research equipment and access to experts in the field.
- Project VTTI-00-033 (Human Factors of Level 3 Automation: Surprise Event Response Evaluation) researchers collaborated with Ford Motor Company to assist in research efforts.
- Project VTTI-00-021 (Signal Awareness Applications) researchers partnered with the Virginia Transportation Research Council (VTRC) and VDOT for financial support and subject matter expert review.
- Project VTTI-00-022 (Automated Truck Mounted Attenuator) researchers collaborated with VDOT, VTRC, and Transurban for cost-sharing. DBi Services provided the truck mounted attenuator truck and equipment for the project.

- Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) researchers partnered with Spin and Ford to receive financial support and assistance in data collection.
- Project VTTI-00-032 (E-Scooter Design) researchers partnered with Spin and Ford to receive financial support and assistance in data collection.
- Project 05-093 (Automated Shuttles and Buses for All Users) researchers collaborated with the City of Arlington Texas for coordination on use of automated shuttles.
- Project 05-086 (A Data Driven Approach to the Development and Evaluation of Acoustic Electric Vehicle Alerting Systems for Vision Impaired Pedestrians) researchers partnered with General Motors for collaborative research support.
- Project VTTI-00-027 (An Evaluation of Road User Interactions with Automated Shuttles) researchers worked with Daimler, Ford, and State Farm for funding, guidance on research questions, and feedback on scenario development.
- Project TTI-05-01 (Connected Vehicle Data Safety Applications) partnered with 3M financial support and General Motors for research support.
- Project 05-109 (ENDEAVRide) researchers collaborated with ENDEAVR Institute and Wocsor LLC for research support and in-kind.
- Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) researchers partnered with Linscott, Law & Greenspan, Engineers and CALTRANS for in-kind and research support.
- North Central Texas Council of Governments provided existing travel demand models to project TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity).
- Project 05-113 (Evaluation Tools for Automated Shuttle Transit Readiness of the Area) members partnered with VDOT for research support.
- State Farm provided research support to members of project VTTI-00-030 (An Evaluation of Road User Interactions with E-Scooters).
- Project 04-104 (Development of a Connected Smart Vest for Improved Roadside Work Zone Safety) collaborated with VDOT to receive research support.
- Project 05-098: Crashworthiness Compatibility Investigation of Autonomous Vehicles with Current Passenger Vehicles authors are collaborating with engineers at the Insurance Institute for Highway Safety to identify crash scenario specifications.

International and Proprietary Collaborators

- Project TTI-Student-07 (Assessment of Work Zone Pre-crash Scenarios Using Crowdsourced Data) researchers partnered with a Nexar based out of Israel for data collection.
- Project VTTI-00-027 (An Evaluation of Road User Interactions with Automated Shuttles) researchers received equipment, engineering, technical review from Daimler out of Germany.
- Project 03-036 (Modeling Driver Responses during AV Platooning Failures) researchers collaborated with Leeds University UK on this project.
- Some Safe-D projects have collaborated with teams in the private industry sector who are unable to be named at the current time due to non-disclosure agreements.

Outputs

The following T2 Performance Goals and corresponding Metrics for Outputs are copied from the currently approved Safe-D T2 Plan. The Safe-D Leadership Team has tracked and will be reporting these metrics in the current and all following SAPRs (Table 2). The Safe-D Website Traffic Measures provide evidence that Safe-D products are being

exposed to practitioners and potential users. The Safe-D website attracted 1,916 visitors during the 6-month reporting period. With the 1,778 visitors during the previous 6-month reporting period, Safe-D greatly exceeded our annual goal of 2,000 visitors per year, with a total of 3,632 visitors from April 1,2020-March 31, 2021. Project Page visits averaged just over 31 visits per page for the 6-month reporting period. At the rate observed during this 6-month period, Project Page visits will fall short of our intended goal of more than 150 Project Page visits per year. The numbers of Project Page visits for the prior two 6-month periods were 39 and 40, indicating a slight decline in the rate of visits but a relatively consistent level of traffic even though the number of overall website visits increased. One possible interpretation is that with the increased number of Project Pages, casual visitors have more pages to choose from and each individual page is receiving less traffic. The Safe-D team will continue to seek ways to raise awareness about the website Project Pages during the next reporting period.

Table 2. T2 Performance Goals and Corresponding Metrics for Outputs

T2 Performance Goal	Goal (Annual)	Measures for Current 6-Month Reporting Period
Website Traffic Measures	Website: ≥ 2,000 visitors/year	1,916; 3,632 visitors/previous 12 mo.
	Project Pages: Average ≥ 150 visitors/year	2,659 total visits/period; average 31 visitors/project page
Journal Articles/Conference Presentations	Project Teams: 1 article/year	17 articles; 0.33 average per reporting project
	Project Teams: 1 conference/year	10 presentations; 0.20 average per reporting project
Facility Tours	Displays viewed by ≥ 200/year	183 total visitor views; average of 3.5 views per reporting project
	Follow-up Interest: 5 visitors/year	8

As in the previous reporting period, COVID-19 has continued to affect facility tours, conferences, and more. Details about how COVID-19 has affected Safe-D projects can be found in the COVID section. Prior to this reporting period, a total of 32 projects had been completed, resulting in 54 journal articles and 92 conference presentations. Within this reporting period, 6 additional projects were completed and a total of 17 new journal articles with 10 new conference presentations were reported by project teams. These additions bring the average rate of publications per completed project to 2 journal articles per project and 2.7 conference presentations per completed project. These rates indicate that Safe-D is tracking ahead of its publication goals for projects through the current reporting period. Safe-D researchers also reported 183 views of Safe-D displays during outreach events during the 6-month reporting period; last period, researchers reported 6,931 views, bringing the yearly total to 7,114, which greatly exceeds with the annual goal of 200 views.

Publications, Conference Papers, Presentations, Books and Thesis

The following are the publications, conference papers, presentations, books and theses that were submitted, accepted, or published during this reporting period.

Journal Publications/Conference Papers

Nasr, V., Wozniak, D., Shahini, F., & Zahabi, M. (2021). Application of Advanced Driver-Assistance Systems in Police Vehicles. Transportation Research Board 100th Annual Meeting Transportation Research Board, (TRBAM-21-00112). (Accepted)

Nasr, V., Wozniak, D., Shahini, F., Zahabi, M. Application of Advanced Driver-Assistance Systems in Police Vehicles. Submitted to Transportation Research Record Journal. (Under review)

Wozniak, D., Shahini, F., Nasr, V., Zahabi, M. Analysis of Advanced Driver Assistance Systems in Police Vehicles: A Survey Study. Submitted to Transportation Research Part F: Traffic Psychology and Behavior. (Under review)

Munira, S., & Sener, I. N. (2021). Examining the spatial variation of the socioeconomic and land-use factors associated with bike activity: A case study using crowdsourced Strava data in Austin, Texas. To be presented at the International Conference on Transport & Health. 14 - 30 June 2021 (Accepted)

Buehler, R., Broaddus, A., Sweeney, T., Zhang, W., White, E., Mollenhauer, M. (2020, July 31). Changes in Travel Behavior, Attitudes, and Preferences among E-Scooter Riders and Non-Riders: Results from Pre and Post E-Scooter System Launch Surveys at Virginia Tech. Transportation Research Board. (Under Review)

Khodadadi, A., Tsapakis, I., Das, S., & Lord, D. Application of Different Negative Binomial Parameterizations to Develop Safety Performance Functions for Non-Federal Aid System Roads. Transportation Research Board Annual Meeting. January, 2021. (Accepted)

Bhadoriya, A. S., Vegamoor, V. K., & Rathinam, S. (2021). Object detection and tracking for autonomous vehicles in adversary weather conditions (No. 2021-01-0079). SAE Technical Paper. (Published)

Alambeigi, H., McDonald, A.D. (2021). A Bayesian regression analysis of the effects of alert presence and scenario criticality on automated vehicle takeover performance. Human Factors: The Journal of the Human Factors and Ergonomics Society. (Accepted)

Sarkar, A., Hickman, J.S., McDonald, A.D., Huang, W., Vogelpohl, T., and Markkula, G. (2021). Steering or braking avoidance response in SHRP2 rear-end crashes and near-crashes: A decision tree approach. Accident Analysis and Prevention. (Accepted)

Sarkar, A., Alambegi, H., McDonald, A.D., Hickman, J.S., and Markkula, G. (2021). Role of Peripheral Vision in Brake Reaction Time During Safety Critical Events. Proceedings of the Human Factors and Ergonomics Society's 2021 International Annual Meeting. (Submitted)

Ghorai, P, Eskandarian, A., Kim, Y.K., and Mehr, G. "State Estimation and Motion Prediction of Other Vehicles and Vulnerable Road Users for Cooperative Perception Based Autonomous Driving: A Survey," in IEEE Transactions on ITS, 2021. (Under Review)

Wu, X., and Eskandarian, A., "Motion Planning of Autonomous Vehicles Under Dynamic Traffic Environment in Intersections Using Probabilistic RRT," in SAE International Journal of Connected and Automated Vehicles, 2021. (Under Review)

Sun, C., and Eskndarian, A., "Predictive Frontal and Oblique Collision Mitigation System for Autonomous Vehicles," ASME Dynamic Systems and Controls Letters, Feb 2021. (Accepted)

Ghorai, P., Eskandarian, A., & Kim, Y. K. (2020, November). Study the Effect of Communication Delay for Perception and Collision Avoidance in Cooperative Autonomous Driving. In ASME International Mechanical Engineering Congress and Exposition (Vol. 84553, p. V07BT07A015). American Society of Mechanical Engineers. (Published)

Khattar, V., & Eskandarian, A. (2020, November). Reactive Online Motion Re-Planning for Crash Mitigation in Autonomous Vehicles Using Bezier Curve Optimization. In ASME International Mechanical Engineering Congress and Exposition (Vol. 84553, p. V07BT07A016). American Society of Mechanical Engineers. (Published)

Alambeigi, H., Smith, A., Wei, R., McDonald, A.D., Arachie, C., Huang, B. (2021). A Novel Approach to Social Media Guideline Design and Its Application to Automated Vehicle Events. Proceedings of the Human Factors and Ergonomics Society 65th Annual Meeting. (Submitted)

Ghanipoor Machiani, S., A. Ahmadi, W. Musial, A. Katthe, B. Melendez, & A. Jahangiri. (2021). "Implications of a Narrow Automated Vehicle Exclusive Lane on Interstate 15 Express Lanes." Journal of Advanced Transportation, Special Issue on "Traffic Safety in Intelligent and Connected Environment." https://www.hindawi.com/journals/jat/2021/6617205/ (Published)

Presentations

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Website(s) or Other Internet Sites

Safe-D Website

During this reporting period, the Safe-D National UTC website was regularly updated with developments from the Safe-D program, including links to project products (e.g., EWD and T2 outputs) and Safe-D outreach activity descriptions. As the website is Safe-D's primary method of external interfacing, the Center is committed to providing up-to-date information through this public website using a modern, minimalist approach to rapid information sharing. The Safe-D website averaged over 309 users per month, with 1,859 new users during this period. Users viewed pages 7,639 times during this period, visiting an average of 2.4 pages per session. These website traffic measures indicate a steady flow of activity, exceeding our T2 performance goals, and this trend is expected to continue as projects complete their activities, and as project products become available for download via the website.

Safe-D Researcher Portal

With 338 users at the end of this reporting period, the Safe-D Researcher Portal continues to successfully facilitate inter-consortium collaboration and access to Center-level resources across our geographically dispersed universities. During this reporting period, Safe-D has seen a decrease in users since the last reporting period due to the removal of some users who are no longer affiliated with Safe-D projects. The Safe-D leadership team has continued to use the portal to disseminate information to project teams and researchers interested in proposing projects to Safe-D. Information on the portal is continually updated so that research team members are aware of upcoming reporting deadlines, processes for the submission of deliverables, and other Safe-D project requirements.

Outcomes

The Safe-D projects described in the previous sections are continuing to contribute to changes to the transportation system by increasing understanding and awareness of transportation issues; guiding future policy, regulation, rulemaking, and legislation; adding to the body of knowledge; training the future transportation workforce; and improving transportation-related processes, technologies, techniques, and skills. Due in part to the strong Safe-D T2 Plan and industry involvement with each Safe-D project, we are starting to the adoption of new technologies, techniques, or practices as a result of Safe-D projects, as outlined in the next sections.

The T2 Performance Goals and corresponding Metrics for Outcomes/Impacts, as found in the currently approved Safe-D T2 Plan, are listed below (Table 3). Although Safe-D project teams dealt with multiple event cancellations due to the COVID-19 pandemic, many Safe-D events have resumed as COVID-19 regulations begin to ease. The Safe-D team participated in 11 outreach events to promote the program and projects to an audience totaling 415 practitioners, including DOT officials, industry partners, and graduate students. Within this reporting period, VDOT and TxDOT have adopted technologies resulting from project 04-113 (Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements). The leader-follower ATMA System technology created under Safe-D project VTTI-00-022 (Automated Truck Mounted Attenuator) has also been applied by VDOT. In general, Safe-D expects the practitioner use of technology to increase as the technological maturity grows. The Safe-D program is currently on-track to meet its T2 performance goals.

Table 3. T2 Performance Goals and Corresponding Metrics for Outcomes/Impacts

T2 Performance Goal	Goal (Annual)	Measures for Current 6-Month Reporting Period
Practitioner Attendance at Events	Project Teams: average 1 event/team	11
	Each Event: average 15 practitioners	415
Vendors Using Technology Developed	Average 1/3 projects result in vendors using technology	1 project has resulted in vendors using technology
	1 license in later stages of UTC operation	0
DOTs Using Technology Developed	3 DOTs using project technology	2 VDOT and 1 TxDOT
	Follow-on funding from 2 DOTs	1

Increased Understanding and Awareness of Transportation Issues

During this reporting period, Safe-D research projects enhanced the understanding and awareness of various transportation issues arising from the increasing implementation of vehicle connectivity, automation, big data analytics, and transportation as a service. Safe-D projects have improved our understanding of various issues surrounding the development and implementation of automated and connected vehicles. The results of Project 05-098 (Crashworthiness Compatibility Investigation of Autonomous Vehicles with Current Passenger Vehicles) will inform testing and evaluation criteria for AVs, and the results are expected to be incorporated into the current IIHS evaluation criteria. The proposed criteria could be used to make design modifications to existing passenger vehicles to increase occupant safety. National standards for the evaluation can be modified and used by the National Highway Traffic Safety Administration (NHTSA) and the Federal Highway Administration (FHWA), as no current protocols exist for the ever-growing fleet of and the presence of AVs entering the market. Project 05-115 (Cooperative Perception of Connected Vehicles for Safety) will enhance our understanding of safety with regard to critical hazards, to help cooperative and connected on-road vehicles avoid crashes. This project will also generate novel path and trajectory planning algorithms for collision avoidance.

There is currently an insufficient amount of connected vehicle testbeds that are not part of a specialized testing environment. As, Project TTI-01-02 (Creating a Smart Connected Corridor to Support Research into Connected and Automated Vehicles) seeks to understand how to integrate specialized equipment with significant constraints into real-world traffic environments, which is critical for eventual widespread deployment. This project will provide a baseline understanding of infrastructure needs and readiness.

Safe-D projects are also enhancing our understanding of the environmental impacts of vehicles. For example, Project TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity) will increase public awareness of the health implications of AVs as well as help city planners, transportation engineers, and health sectors understand these health implications based on changes in air quality and motor vehicle crashes. This project will also produce tools and methodologies for assessing the impacts of AVs on health and investigate the equity in these AV health impacts to formulate equitable policies for AV adoption.

Transportation Safety for At Risk Populations

Safe-D projects have made significant contributions to the understanding and awareness of at-risk populations such as individuals with disabilities. For example, Project 05-086 (A Data Driven Approach to the Development and Evaluation of Acoustic Electric Vehicle Alerting Systems for Vision Impaired Pedestrians) is influencing decisions made by an SAE cooperative research project (CRP) that is formulating changes to additive warning sound regulations in the U.S. and the E.U to make vehicle detectability easier for vision impaired and/or potentially distracted pedestrians. The SAE CRP consists of members from SAE, Mercedes Benz, General Motors, Nissan, Toyota, Honda, BMW, Virginia Tech, Siemens, Head Acoustics and Brüel & Kjær. Under Project 05-093 (Automated Shuttles and Buses for All Users), Safe-D researchers are working with personnel from the city of

Arlington, Texas, the service provider, and other groups to introduce an automated RAPID shuttle (launched on March 23, 2021) to individuals with disabilities. The results will increase our understanding of transportation issues and opportunities, including complete trip information, for disabled individuals, and provide guidance for how communities and service providers can improve travel opportunities.

During this reporting period, Safe-D Project 05-109 (ENDEAVRide) raised awareness of how emerging transportation technologies such as AVs can help small, rural communities (see the ENDEAVRide YouTube Channel for details). The outcomes have already inspired various stakeholders to support and sustain ENDEAVRide in Nolanville, Texas and surrounding communities. This project will likely inspire entrepreneurs from Central Texas and beyond to explore the use of AVs and telemedicine technologies to serve underserved populations.

Passage of New Policies, Regulation, Rulemaking, or Legislation

The results of several Safe-D projects have contributed to new policies, regulations, rulemaking, or legislation during this reporting period or are currently being considered in regulations or legislation. For example, the demonstration of mobile applications in Project (VTTI-00-021 Signal Awareness Applications) will showcase to VDOT stakeholders an example use case where the signal phase and timing (SpaT) and MAP data being transmitted by connected intersections in the Virginia Connected Corridors system can be utilized by end users in a mobility application. Upon a successful demonstration, VDOT and other stakeholders will have the opportunity to fund further development and expanded mobility application use cases and eventually safety application use cases.

Increases in the Body of Knowledge

Safe-D projects have made meaningful contributions to the body of scientific knowledge during this reporting period. For example, Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) is greatly affecting the body of knowledge surrounding micromobility. Little formal research has been conducted on e-scooters; this study will provide the first naturalistic dataset derived from e-scooters. The results will improve our understanding of e-scooter safety, possibly leading to new policies and regulations for e-scooter deployments in addition to recommended designs and procedures for e-scooter companies. Another study focused on e-scooters, Project VTTI-00-032 (E-Scooter Design), is developing benchmark tests for evaluating e-scooter designs. The resulting recommendations for the optimal design can be used by e-scooter developers to help reduce safety concerns.

The models developed under Project 03-036 (Modeling Driver Responses during AV Platooning Failures) will be made available to government and stakeholders for use in the design of new AV technologies. The experimental findings improve our understanding of AV failures and driver responses to rear-end emergency scenarios. Project VTTI-00-022 (Automated Truck Mounted Attenuator) will increase our understanding of the dangers posed to the drivers of TMA vehicles and will create new technology that can be expanded to use in real-world work zones to eventually remove the driver from that dangerous position in the TMA vehicle once it is fully automated and will enlarge the pool of trained professionals who are knowledgeable about and can operate the ATMA System.

Improved Processes, Technologies, Techniques, and Skills in Addressing Transportation Issues

Numerous Safe-D projects have generated processes and technologies that can be applied to improve transportation safety. Project TTI-05-02 (Analysis of Advanced Driver-Assistance Systems in Police Vehicles) surveyed 73 police officers to assess their opinions on various ADAS as well as their recommendations for improvement. The results suggest that officer behavior and intention to use ADAS features are influenced by the trust officers have in the available ADAS, among other factors such as ADAS training and perceived usefulness. Based on these findings, guidelines for development of ADAS were provided to improve ADAS in the next generation of police vehicles and increase officer driving safety in police operations.

Project 04-115 (Reference Machine Vision for ADAS Functions) led to improved understanding of the challenges involved in lane detection and following technologies and the infrastructure required to support these technologies. The team developed a comprehensive dataset to evaluate different types of lane markings and relate their material properties to lane detection performance. The results were presented in a panel discussion organized by the 2020 IEEE-ITSS and ITE joint effort on "Development of Needs and Scope for Cooperative infrastructure-Vehicle Detection and Localization for Automated Vehicles."

Project 04-101 (Safety Impact Evaluation of a Narrow-Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) is helping to shed light on the barriers and opportunities AVs bring to existing infrastructure. The project team has established a baseline functional safety concept for the future development of AV-exclusive lanes and adapting infrastructure to AV technology. This could lead to the development of new regulations and guidelines for implementation considerations and design specifications of AV-exclusive reversible lanes.

Adoption of New Technologies, Techniques, or Practices

During this reporting period, numerous Safe-D projects have contributed to the adoption of new technologies, techniques, and practices. For example, vehicle trajectory prediction models from Project SDSU-01-01 (Prediction of Vehicle Trajectories at Intersections Using Inverse Reinforcement Learning) were developed using different machine learning methods. The models can be used at intersections to predict future driver behavior, leading to infrastructure-based safety monitoring systems for proactive safety evaluation. The models can also be used to identify violations such as red-light running. The findings of this project will increase our understanding of model development based on machine learning for predicting vehicle trajectories.

Project 05-097 (Investigating and Developing Methods for Traditional Participant-based Data Collection with Remote Experimenters) is developing remote experimentation tools, some of which have already been applied in other VTTI projects. We anticipate that these tools will be vital in the future for certain kinds of research as these tools have the potential to enhance data quality in transportation technology research.

Impacts

Impact on Effectiveness of Transportation System

Safe-D research projects are designed to produce implementable results that have both near-term and long-term effects on the transportation system. Although the results of some Safe-D studies have only recently begun to be implemented and/or disseminated to practitioners, the outcomes of some projects are beginning to influence our transportation system. For example, the outcomes of 04-115 (Reference Machine Vision for ADAS Functions) have the potential to prevent or mitigate 483,000 crashes in the United States every year, including 87,000 nonfatal injury crashes and 10,345 fatal crashes. While lane departure warning (LDW) and lane keeping assistance (LKA) systems are available, the customer acceptance and market penetration of these technologies have been low. These deficiencies can be traced to the inability of many of the perception systems to consistently recognize lane markings and localize the vehicle with respect to the lane markings in real-world environments, resulting in inconsistent detection, misidentification, and/or inability to locate lane markings in some conditions. These challenges can be addressed both by improving the consistency and detectability of the lane markings and by improving the perception algorithms currently employed in the sensors. Currently, there is no available standard or benchmark to evaluate the quality of either the lane markings or the perception algorithms. This project is address this gap by developing a reference lane detection system as a benchmark for evaluating the effectiveness of different lane markings and perception algorithms to reliably engage LDW and LKA systems.

The guidelines developed in project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety) assist in recognizing the misuse of AV technologies (e.g., YouTube videos of drivers dancing in the back seat of a Tesla in

autopilot mode) and apprehension among the public about using AV technologies. The findings will illustrate how these feelings traverse social media and provide guidelines to properly calibrate driver expectations. This calibration should lead to safer use of AVs and fewer crashes.

Provision of tools/methodologies for practitioners

Safe-D projects have provided or are expected to provide new tools and methodologies that can be applied by practitioners to enhance the effectiveness of the nation's transportation system. Some examples include the following:

- The vehicle trajectory prediction models at intersections developed in project SDSU-01-01 (Prediction of Vehicle Trajectories at Intersections Using Inverse Reinforcement Learning) will contribute to safety monitoring systems.
- The system developed in project VTTI-00-022 (Automated Truck Mounted Attenuator) will likely result in further development by VDOT and/or the private industry partners involved in this project, with the ultimate goal of deploying the system in live work zones. This technology will be offered to the private industry partners to license in the future.
- The results of Project 05-093 (Automated Shuttles and Buses for All Users) will assist in better understanding the needs of disabled individuals in the design and operation of automated shuttles and buses. It will also identify barriers in the built environment to travel by disabled individuals.
- Project 05-098 (Crashworthiness Compatibility Investigation of Autonomous Vehicles with Current Passenger Vehicles) is examining AVs that carry goods such as groceries and fast food. The crashworthiness criteria can be utilized to make additions or modifications in existing criteria by the government agencies to put some restrictions on speed or structure of other passenger vehicles that might interact with these AVs.
- The system developed under Project VTTI-00-036 (Smart Work Zone System) uses connected vehicle-to-everything (C-V2X) technology and can be adopted by original equipment manufacturers (OEMs) to allow them to communicate with infrastructure or directly with vulnerable road users. The Smart Vest product can be adopted by DOTs or other entities interested in deploying this device in work zones.
- The results of Project VTTI-00-025(Radar and LiDAR Fusion for Scaled Vehicle Sensing Test) will enhance products at Continental Automotive.
- Project 05-091 (Improving Methods to Measure Attentiveness through Driver Monitoring) is developing algorithms and supporting guidelines that can be applied in driver monitoring systems to effectively determine driver awareness in real time.
- Project TTI-01-02 (Creating a Smart Connected Corridor to Support Research into Connected and Automated Vehicles) will enhance the deployment of connected vehicles on real roadways and provide substantive benefits to IOOs seeking to deploy connected vehicles and infrastructure.
- The vehicle intrusion alert system developed in Project TTI-05-03 (Development of a Roadside LiDAR-Based Situational Awareness System for Work Zone Safety: Proof-of-Concept Study) may lead to a commercialized product in the area of smart work zone safety.
- Project VTTI-00-030 (An Evaluation of Road User Interactions with E-Scooters) is evaluating e-scooter and other road user interactions to assess safety and identify potential countermeasures to improve safety for e-scooter riders and road users. The findings will contribute to regulations on e-scooter riding behavior.

Impact on Adoption of New Practices or Initiation of Startups

Before research begins on each Safe-D project, a T2 plan is developed that details how the outcomes of the project will be translated for public use or commercialization. The development of the T2 plan and the eventual commercialization of the results are facilitated by both Safe-D T2 Coordinators, Dr. Mike Mollenhauer and Luke Neurauter. While no start-up companies have been created at this point as a direct result of Safe-D projects, opportunities for commercialization have been identified and will be pursued as the research products are further developed. Beyond commercialization, Safe-D projects are expected to lead to the adoption of new practices in various transportation-related areas as the results and outcomes are disseminated. For example, results from Project 04-113 (Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements) will be

used by FHWA to determine whether probe-based volumes can replace traditional traffic volumes that transportation agencies collect in the field. Private vendors such as INRIX, StreetLight, and Wejo will also benefit from this project, which has demonstrated that the accuracy of these probe-based estimates has significantly improved and will likely continue to improve over the next few years. We expect the probe-based estimates to dominate the traffic monitoring industry in the next decade.

There is also a large marketplace for AVs. For instance, the ongoing COVID-19 pandemic calls for robust, human-less delivery systems. Project 05-087 (Autonomous Delivery Vehicle [ADV] as a Disruptive Technology: How to Shape the Future with a Focus on Safety?) researchers are interacting (via teleconference or webinar) with ADV companies throughout the project to discuss data sharing, potential safety implications, and policy related issues. The results will attract other ADV companies to fund additional rigorous investigations. The interactive decision support tool will also have tremendous value for the interested parties.

The outcomes of Project 04-103 (Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: Phase II) should be eye-opening for all OEMs and other purveyors of ADAS technologies. Based on actual on-road data, this project has shown that technological innovations can indeed improve the driving performance of older adults along one or more dimensions. However, it was disconcerting to learn that other dimensions of driving performance may have been simultaneously impacted in a less desirable manner. Further work is required to refine the implementation of these technologies so that their full potential can be realized across the broad spectrum of drivers. This study has inspired a much larger related project sponsored by NHTSA.

The potential for commercialization and adoption of new practices resulting from other Safe-D projects are summarized below:

- The findings of Project 05-113 (Evaluation Tools for Automated Shuttle Transit Readiness of the Area) will assist in future deployment planning and evaluation of pilot programs, possibly changing or establishing new regulations on low-speed automated vehicle deployment. Automated transit buses will also benefit from the results of this study.
- Project VTTI-00-027(Impact of Automated Vehicle External Communication on Other Road User Behavior) will influence the technology used within personal vehicles and the public usage of the data. The results related to external communication will be applicable to both government (policy and specifications) and industry (implementation and design).
- Project 05-109 (ENDEAVRide) will likely inspire entrepreneurs from Central Texas and beyond to explore the area of using AV and telemedicine technologies to serve underserved populations.
- The application developed in Project VTTI-00-021 (Signal Awareness Applications) is planned for public deployment in the VCC through the Google Play Store and/or Apple store.
- The methods developed in project TTI-05-01 (Connected Vehicle Data Safety Applications) have been successfully employed in a TxDOT roadway safety and access management project in West Texas. The TxDOT project in West Texas is likely to be replicated and expanded with the Odessa District and other areas of the state.
- The results from project VTTI-00-027 (Impact of Automated Vehicle External Communication on Other Road User Behavior) will be transferred to industry partners including Daimler, Ford, and State Farm along with other UTC stakeholders.

Impact on the Body of Scientific Knowledge

Through basic and applied research focused on four key disruptive technologies (connected vehicles, automated vehicles, transportation as a service, and big data analytics), Safe-D projects are expected to make meaningful contributions to the body of scientific knowledge within the broad area of transportation. For example, Project 04-103 (Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: Phase II) collected and analyzed real-world driving data to inform the questions driving research in the ADAS space. The findings regarding the mixed effects of adaptive cruise control (ACC) contribute to the understanding of how ADAS should be presented to

senior drivers to promote their optimal use. This project also produced case study teaching materials for an introductory graduate class, ISE 5604-Human Information Processing, and an undergraduate class, ISE 3614-Introduction to Human Factors Engineering. In both courses, the Safe-D-supported studies illustrate, using the example of driving, that exposure to ADAS can help seniors better accept and use such technologies, although their effects on mobility and safety for this population of users are not fully understood.

The semi-supervised topic filtering method developed in Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety), examined the Twitter search process, represents a significant advancement in computer science and social media analysis. Finding relevant data on social media is a challenge, and this method significantly improves upon prior benchmark methods. Furthermore, while there have been multiple surveys of drivers' feelings regarding AVs, this analysis is the first documented analysis of how these feelings translate to social media and how they change with significant events. The lessons learned will inform subsequent experiments and analyses of AV safety and illustrate some significant limitations of prior social media analyses of AV crashes (e.g., sentiment dictionaries developed for general discourse are not effective for AV analyses).

Currently, there are limited scientific studies on the new infrastructure standards for the safe and efficient deployment of AV technology on existing roadways. Project 04-101 (Safety Impact Evaluation of a Narrow-Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) gathered foundational research data to inform the development of AV-compatible infrastructure. The recommendations and guidelines generated for the implementation of narrow AV-exclusive reversible lanes will contribute to the development of new infrastructure standards. The recommendations detail the considerations that should be addressed when designing AV-exclusive lanes, critical characteristics of AVs affecting narrow lane considerations, and a real-world example (I-15 smart corridor case study).

Project VTTI-00-027 (Impact of Automated Vehicle External Communication on Other Road User Behavior) has provided data on effective forms of external communication based on evaluations of different configurations of external communication. This information can be transferred to other AV uses (e.g., personal vehicles, public/shared vehicles, and construction).

Project 05-086 (A Data Driven Approach to the Development and Evaluation of Acoustic Electric Vehicle Alerting Systems for Vision Impaired Pedestrians) is developing novel methods to broadcast additive warning sounds, new types of additive warning sounds, and statistical measures the effectiveness of additive warning sound systems. Based on the findings, the team will provide recommendations to governmental regulators for implementing warning sounds in electric vehicles and evaluating compliance by auto manufacturers.

Impact on Transportation Workforce Development

Each Safe-D project includes an individually created EWD plan guided by the EWD Coordinator, Dr. Miguel Perez. The EWD plans ensure that Safe-D projects generate significant impacts on the future transportation workforce by providing opportunities for teaching and education; building experience and skill among underrepresented groups in the transportation profession; and exposing practitioners, teachers, and members of the public to science and technology as they relate to Safe-D research. During this reporting period, Safe-D projects have (1) generated valuable educational opportunities for students of varying age groups, including students in underrepresented groups and (2) led to the development of curriculum materials for educators. Specific examples of how Safe-D projects have contributed to EWD are provided below.

Learning experiences and building the future for the next generation

Safe-D projects have contributed to the development of the transportation workforce through direct engagement with both K-12 students and older students at the undergraduate and post-graduate levels. For example, Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) gave students involved in the project the opportunity to become familiar with infrastructure design, safety

considerations, traffic operations, and AV technology. Students had the chance to convey their ideas and questions to the project researchers and improved their oral and written communication skills by documenting the research method and findings. Problem characteristics, research approach, and findings were summarized into a teaching module, which will be incorporated into the curricula of transportation courses at SDSU and made available to the other consortium members for inclusion in appropriate courses at Virginia Tech and Texas A&M. The industry partner, LLG, plans to present the study at local transportation professional organizations to educate the workforce on the growing role of AVs and their integration into the mainstream transportation infrastructure.

A PhD and undergrade student will benefit from project 05-087 (Autonomous Delivery Vehicle as a Disruptive Technology: How to Shape the Future with a Focus on Safety?), which focused on the methods of collecting data from disruptive technologies in the field of engineering. The project is expected to generate at least one MS/PhD dissertation topic. The students will also learn new tools for collecting and analyzing data from multidisciplinary sources. The students will learn industry level data integration methods using Azure Databrick, or AWS. Additionally, Google Colab will be extensively used to train the students. The students will also acquire hands-on experience with deep learning algorithms from this project.

Many other Safe-D projects have also provided valuable hands-on experiences for undergraduate and graduate students, including the following:

- Project TTI-Student-08 (Identifying Deviations from Normal Driving Behavior) will help a doctoral student gain knowledge in the fields of transportation engineering, data science and analytics, and environmental engineers. The research findings will also be disseminated to students through webinars and conference presentations.
- Project VTTI-00-030 (An Evaluation of Road User Interactions with E-Scooters) involves one part-time graduate research assistant, who is learning how to conduct naturalistic driving coding and analysis.
- Under Project VTTI-00-025 (Radar and LiDAR Fusion for Scaled Vehicle Sensing Test), Masters student Gregory Beale had the opportunity to apply advanced analytical techniques to a real-world problem and demonstrate the applicability of these techniques in an important area of transportation research. He will use this experience in his continued career as an automotive engineer, where he expects to continue developing technologies that assist drivers and/or automate portions of the driving task. In the earlier parts of the project, the team also exhibited these technologies to K-12 students, some of whom expressed interest in pursuing similar areas of study in their continued education.
- A Masters student involved in Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) has gained first-hand knowledge of naturalistic data collection studies and experience working with industry sponsors. This dataset can be used by other researchers to answer other research questions, providing additional opportunities for workforce development in the future.

Development of Educational Tools and Courses

In addition to the students working directly on Safe-D projects, Center research has reached a broader spectrum of students through the development of educational materials and content for college courses. These outputs range from teaching modules to classroom exercises based on real-world problems to web-based presentations. Specific examples of educational content produced by Safe-D projects in this reporting period are summarized below:

- The findings of Project 05-084 (Behavioral Indicators of Drowsy Driving: Active Search Mirror Checks) are being incorporated into a learning module discussing the role of Driver Monitoring Systems and the study of PERCLOS as educational course materials.
- The results from Project VTTI-00-030 (An Evaluation of Road User Interactions with E-Scooters) will be the focus of a lecture in the Human Factors and Transportation Class (Spring 2022) as an example of how to study user interactions with novel forms of microtransit.
- The findings from Project 05-113 (Evaluation Tools for Automated Shuttle Transit Readiness of the Area) will be the focus of a lecture in the Human Factors and Transportation Class (Fall 2021) as an example of

how to study interactions between automated driving systems and other road users and infrastructure. This project will also be used as an example in the Safety System Analysis Class of how risk assessment can be done using naturalistic data and how it can be applied to the planning of future traffic systems.

- Findings from Project 05-097 (Investigating and Developing Methods for Traditional Participant-based Data Collection with Remote Experimenters) will be made available to researchers everywhere, enabling them to perform remote experimentation if this model fits their data collection needs. This will facilitate skills development for new researchers and potentially create a new class of experimenters (remote experimenters) with unique skills and responsibilities compared to traditional in-vehicle experimenters.
- Project 05-101 (Evaluation of transportation safety against flooding in disadvantaged communities) will contributed to the development of materials for K-12 students from disadvantaged communities around San Diego through SDSU's STEM Exploration Day. The materials will aim to attract students to STEM disciplines, specifically flood control and transportation safety, for building a diverse future workforce.
- The advanced statistical framework developed under Project 03-049 (Data Fusion for Non-Motorized Safety Analysis) will be incorporated into the teaching curricula of transportation courses.

Workforce Development Activities

Beyond engagement with students, Safe-D projects have contributed to the education of the existing transportation workforce as well as the development of the future workforce. As noted, COVID-19 regulations have made it difficult for researchers to conduct real time in-vehicle experiments with participants, thus creating a need to develop solutions to address this issue. For example, findings from Project 05-097 (Investigating and Developing Methods for Traditional Participant-based Data Collection with Remote Experimenters) will be made available to researchers everywhere, enabling them to perform remote experimentation if this model fits their data collection needs. This could allow skills development for new researchers and potentially create a new class of experimenters (remote experimenters) who have a different set of skills and responsibilities than traditional in-vehicle experimenters.

Changes/Problems

Changes in Approach

Given the stresses of today's fast-paced and academically rigorous environment, Safe-D has begun to search for ways to make research teams' experience with Safe-D easier. For example, quarterly reports have been switched to survey format instead of a document format. Switching to a survey format allows researchers to complete a more condensed version of the quarterly report and bypass questions that are not applicable to them. Nearly 70% of the researchers approve of the change. This has also made it easier for administrative members to easily access quarterly reports from their consortiums. Safe-D will also develop a separate Bi-Annual Activity survey for completed projects to capture T2 and EWD information, such as industry and vendors use of technology. Before Safe-D issued the same survey to active and completed project which led to confuse and low response rate from the complete projects. Safe-D believes that implementing a separate and shorter survey for complete projects will increase the survey response from complete projects. Safe-D plans to continue to look for other areas to improve the overall satisfaction of the researchers involved with Safe-D projects.

Actual/Anticipated Problems/Delays

Impact of COVID-19

Safe-D output goals such as facility tours, workshops, etc., have continued to struggle due to COVID-19. Cancellations, postponements, and adjustment to virtual methods for these output measures have not deter Safe-D from achieve success in reaching our goals. However, as the rules and regulations to COVID-19 begin to lessen, Safe-D believes these metrics will continue to be met if not surpassed. During this reporting period, 22 Safe-D projects reported that research activities had been impacted by COVID-19 in some way. Among these projects, 8

reported minor impacts, 11 reported moderate impacts, and 4 reported significant impacts from COVID-19. Projects that were impacted by COVID-19 reported the biggest effects from July through December. Although some states have begun to relax COVID-19 restrictions and as amount of vaccination increase, many of these impacts can still be attributed to the social distancing measures and travel restrictions put in place in response to COVID-19. Below are some specific examples of how COVID-19 has affected Safe-D projects along with some solutions:

Safe-D Projects Reporting Minor Impacts

- Project 04-115 (Reference Machine Vision for ADAS Functions) data collection and processing were delayed a bit because we could not hire student workers in the summer.
- Project 05-093 (Automated Shuttles and Buses for All Users) RAPID shuttle implementation in Arlington was pushed back from late 2020 to March 2021.
- Project 05-096 (Curb Management Practices and Effectiveness in Improving Safety) focus groups will have to be conducted virtually due to the COVID-19 pandemic. However, the focus group sessions may be conducted in person and sessions can be conducted safely relative to current CDC guidance and state/county protocols.
- Data collection was terminated early due to COVID-19 and a project extension was granted for Project VTTI-00-026 (Guiding Driver Responses During Manual Takeovers from Automated Vehicles). However, within-subjects design of the project had greater statistical power than a between-subjects design. As a result, fewer participants were necessary, meaning that the early terminations yielded no noticeable impact on the outcomes.

Safe-D Projects Reporting Moderate Impacts

- Project TTI-05-02 (Analysis of Advanced Driver-Assistance Systems in Police). Researchers experienced delay and some modifications in phase 1. The ride-along surveys were updated to online format. The project could not conduct the focus group with officers and had to collect data through an online survey study instead. The project still plans to start the data collection for the phase 2 study (which is a driving simulation study) in the summer. Researchers are currently in the process of submitting the documents to the Internal Review Board for this study but are not sure how much time the approval and the human subject testing might take due to COVID-19.
- Project VTTI-00-022 (Automated Truck Mounted Attenuator). An extension had to be requested due to the COVID-19 pandemic regulations. However, CVOID-19 protocols have been implemented for testing/demonstrations performed. (i.e., only one person allowed in vehicle).
- Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning). The scooter deployment on the VT campus was cancelled at the onset of COVID-19 when the students were sent home in March. The project team is working with stakeholders to determine if/when the scooters can be redeployed on the VT campus and/or in another location to complete data collection, which was cut short by 5 months. The team is working on starting another deployment in the summer of 2021 to collect additional data.
- Project (VTTI-00-027 Impact of Automated Vehicle External Communication on Other Road User Behavior). In order to complete our human subjects test, we had to make modifications to our testing methods. For example, face coverings were required at all times throughout the entire session, a plexiglass barrier between seating rows was installed, at all times the HVAC was on for fresh air supply with all windows opened. Additionally, due to the delay in data collection from COVID-19 from fall to winter, the weather, and winter Holidays, scheduling became difficult. This caused sessions to be canceled and rescheduled, prolonging data collection.
- Project 04-117 (A Sensor Fusion and Localization System for Improving Vehicle Safety In Challenging Weather Conditions). Researchers had to adjust the timeline of the project to accommodate for the time lost because of the shelter in place regulations due to COVID-19.

- Project 05-115 (Cooperative Perception of Connected Vehicles for Safety). Researchers had to postpone experimental verification and validation work due to COVID-19.
- Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety Data). Researchers were forced to truncate an experiment that would further contribute to the design process due to the COVID related research shutdown. The project team has begun using open ended surveys rather than conducting interviews with Public Information Officers.
- Project TTI-01-02 (Creating a Smart Connected Corridor to Support Research into Connected and Automated Vehicles). COVID-19 has slowed down work efforts, made field work harder, prolonged equipment procurement timeframes, and more.
- Project TTI-05-03 (Development of a Roadside LiDAR-Based Situational Awareness System for Work Zone Safety: Proof-of-Concept Study). Students are not allowed in TTI Headquarters or the UMS lab area because of COVID-19. However, the undergraduate and graduate students have been successful in working from home on the assigned tasks and communicating virtually. The researchers also anticipate some delay when implementing the system in the field: a real work zone environment. Researchers may spend more time for finding the appropriate site, coordinating with the local agency, and performing the experimental work.

Safe-D with Significant Impact

- Project VTTI-00-024 (Characterizing Level 2 Automation in a Naturalistic Driving Fleet). Due to the challenges imposed by the Covid-19 pandemic, data collection for the original target project was suspended and the team had to pivot to a different naturalistic data collection project, which has been slower than expected to collect data and does not have all the measures that the research team originally expected. Consequently, the data collection and analysis is behind the schedule outlined in the original study work plan. The research team anticipates that a no cost time extension of approximately 12 months will be needed in order to complete the project.
- Project TTI-04-02 (Delving into Safety Considerations of E Scooters: A Case Study of Austin, Texas). Due to COVID-19, this project has been on hold, primarily since the research team was not able to reach their contacts at the medical center to access data. Based on discussions with the medical staff, the Principal Investigator anticipates resuming the research soon in the next reporting period.
- Project 04-110 (Developing an Intelligent TMC with a Safety Evaluation Focus for Smart Cities). Project Scope has been reduced, and an extension request has been submitted with an updated timeline table.
- Project 05-109 (ENDEAVRide). Researchers are holding the study participant enrollment work due to older adults' low willingness to travel and interact with study staff. The project expects to start the enrollment in late May once a large proportion of the population is vaccinated.

Overall, the main outcome of the above effects of COVID-19 is the expected delay of some Safe-D research projects. The Safe-D administration is working individually with each project team to determine how to best adjust project activities to minimize delays and ensure continued research progress. Where possible, meetings and other project activities will be shifted from in-person to virtual. In some cases, project tasks may be able to be restructured to avoid significant delays. However, more time has been given for certain projects that rely on the collection of participant data or other in-person interactions, and certain project tasks reliant on human subject data. Human subject research has been approved by the Institutional Review Board to run again with strict guidelines. These guidelines include temperature checks, glass/plastic partitions in vehicles, and sanitation between vehicles, all of which add more times to the overall studies.

Changes Affecting Expenditures

Nothing to report.

Changes in Study Protocols

Nothing to report.

Changes in Performance Site Location

Nothing to report.

Special Reporting Requirements

N/A