SEMI-ANNUAL PERFORMANCE REPORT

OCTOBER 2019 TO MARCH 2020

SAPR #6

SAFE-D: SAFETY THROUGH DISRUPTION UNIVERSITY TRANSPORTATION CENTER

SAN DIEGO STATE UNIVERSITY

Texas A&M Transportation Institute

VT VIRGINIA TECH TRANSPORTATION INSTITUTE

Federal Agency	Office of the Secretary of Transportation (OST); U.S. Department of Transportation (US DOT)
Federal Grant Number	69A3551747115
Project Title	Safety through Disruption (Safe-D) National University Transportation Center
Program Director Name, Title, and Contact Information	Dr. Zachary R. Doerzaph zdoerzaph@vtti.vt.edu (540) 231 – 1500
Name of Submitting Official	Leslie Harwood, M.S. Program Manager, Safe-D National UTC lharwood@vtti.vt.edu (540) 231 – 9530
Submission Date	April 30, 2020
DUNS / EIN	0031370150000 / 54-6001805
Recipient Organization	Virginia Tech Transportation Institute
Recipient Identifying Number	N/A
Grant Period	November 30, 2016 – September 30, 2022
Reporting Period End Date	March 31, 2020
Report Term/Frequency	Semi-annual reporting periods
Signature of Submitting Official	

Table of Contents

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.

Accomplishments During This Reporting Period

Project Awards and Activity

The Safe-D competitive award process employs a rigorous peer review process, including reviews by the Safe-D Leadership Team at both the Research Statement and full Work Plan stages and a review of invited pitch presentations by the Safe-D Stakeholder Advisory Board. While Safe-D did not solicit research proposals during this reporting period, both VTTI and TTI funded multiple directed projects. Directed projects are awarded by the Safe-D team mid-year based on a high impact merit, strong collaborators, and resource availability. Nearly all awards made 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 Wejo, Continental Automotive, GM, State Farm Insurance Corporation, and the Robert Wood Johnson Foundation.

At the end of this reporting period, the Safe-D National UTC had a project portfolio of more than $16.6 million, with nearly 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 1 (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%).

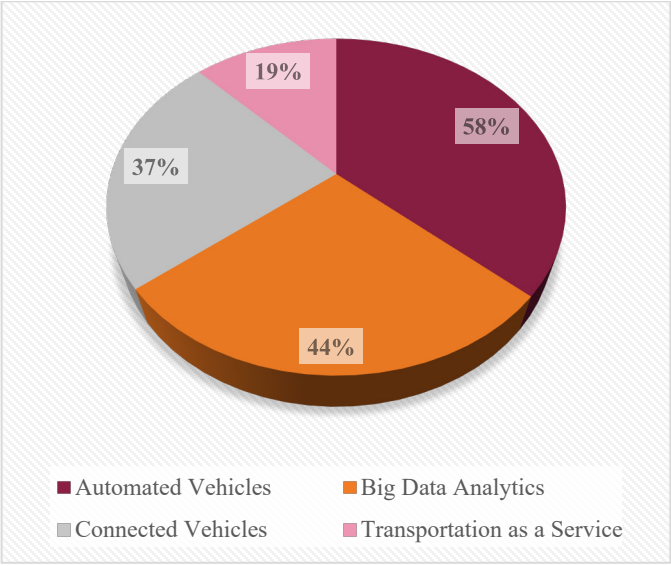

Figure 1. Portfolio of Safe-D Projects by Theme Area (total exceeds 100% due to projects covering multiple theme areas)

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 (*denotes lead institution).

Project VTTI-00-025: Radar and Lidar Fusion for Scaled Vehicle Sensing

Institutions: VTTI; Award Round: Directed; Theme Area(s): Automated Vehicles, Transportation as a Service*

The goal of this project is to test the effectiveness of combining radar and lidar in small scale testing models to improve overall reliability and accuracy of advanced driving assistance systems (ADAS) in the testing environment. Scaled vehicle testing is important in researching ADAS, as it provides flexibility and control of the environment and reduces the risks and expenses associated with full scale vehicle testing. This project will help researchers identify safety concerns with ADAS more quickly, leading to faster and safer development of implementable products.

Project VTTI-00-029: Real-World Use of Automated Driving Systems and their Safety Consequences

Institutions: VTTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*

This project will address misconceptions surrounding the capabilities and limitations of automated driving systems (ADSs). The goal of this project is to determine the uses, benefits, and negative consequences of using early ADSs, currently available to consumers, on the public roadways. This project will analyze 50 individuals and their personal driving habits concerning the use of ADSs in real-world operation. This project will work to better inform researchers of the real-world benefits as well as unintended consequences of early ADSs currently in use on the roads. The study will work to better understand driver behaviors and their use of ADSs in order to further develop human-machine interfaces, training programs, and owner's manuals to reduce negative consequences of unintended ADS use.

Project VTTI-00-030: An Evaluation of Road User Interactions with E-Scooters

Institutions: VTTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*

The primary objective of this project is to evaluate e-scooter rider interactions with other road users by data mining the fixed camera video database that is currently being collected on Virginia Tech's Blacksburg campus by Safe-D project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning). Using three or four strategically fixed cameras located proximal to campus bus stops, the data will be reviewed to 1) determine e-scooter presence 2) capture e-scooter interactions with other road users, 3) classify these interactions for severity and 4) record general behavior of e-scooter riders (e.g., helmet use, backpack/carriage of other items, speed, following general rules of road). Analyses will provide greater understanding of e-scooter rider interactions with other road users and potential countermeasures to improve safety for all road users.

Project TTI-05-01: Connected Vehicle Data Safety Applications

Institutions: TTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*

The objective of this project is to explore roadway safety applications of connected vehicle data provided by Wejo for July and October 2019 for the entire state of Texas. Wejo is a connected vehicle data vendor that aggregates data from automotive manufacturers and then licenses its use to customers. The Wejo data consist of vehicle movement data with 3-second waypoint frequency and driver event data for individual vehicle trips. From these, this project will look at actual travel speeds, seat belt usage, harsh braking/acceleration by date/time, location, and vehicle year/make/model. Crash data will be spatially related to driving events to explore possible statistical relationships between driving events/behavior and crash risk.

Project TTI-05-02: Analysis of Advanced Driver-Assistance Systems in Police Vehicles

Institutions: TTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*

The objective of this project is to evaluate ADAS in police vehicles. This project will investigate how ADAS features should adapt in situations of multi-tasking and what types of ADAS are most effective for improving driver safety. This project includes two phases: (1) ADAS needs and implementation analysis in police vehicles; and (2) evaluation of police ADAS in a driving simulation study. The first phase includes ride-along observations and

focus group meetings with officers to understand their ADAS needs and current systems in police vehicles. The second phase will evaluate ADAS in high-demand situations using a high-fidelity driving simulator.

Project TTI-05-03: Development of a Roadside Lidar-Based Situational Awareness System for Work Zone Safety: Proof-of-Concept Study

Institutions: TTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*
The objective is to develop a set of algorithms to collect and interpret real-time information of each approaching vehicle and worker (e.g., location, speed and direction) in and outside of work zones using the roadside lidar sensing equipment. Ultimately, the outcome of this study will produce a full-scale warning system that is deployable in a real work zone environment. Such a system can detect and analyze live traffic and work zone activity, activate the appropriate warning scheme, and deliver information to roadway workers in work zones so that they can take evasive actions instead of passively relying on traditional safety countermeasures

Project TTI-Student-06: Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity

Institutions: TTI; Award Round: Directed: Theme Area(s): Automated Vehicles, Big Data Analytics*
The goal of this study is to attempt to quantify automated vehicles' (AVs') impacts on public health and health equity through the changes they effect in transportation. The research team will focus on two risk factors—motor vehicle crashes and air pollution—to measure AV's effects on public health and health equity.

Completed Projects

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

- 02-009 (Vehicle Occupants and Driver Behavior: An Assessment of Vulnerable User Groups)
- 03-082 (Assessing Alternative Approaches for Conveying Automated Vehicle 'Intentions')
- TTI-01-01 (Analysis of an Incentive-Based Smartphone App for Young Drivers)
- TTI-Student-02 (Development of Analytic Method to Determine Weaving Patterns for Safety Analysis near Freeway Interchanges with Access Management Treatments)
- VTTI-00-020 (Standardized Performance Evaluation of Vehicles with Automated Capabilities)

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 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:

- 01-003 (Data Mining to Improve Planning for Pedestrian and Bicyclist Safety)
- 01-006 (Implications of Truck Platoons for Roadside Hardware and Vehicle Safety Hardware)
- 02-008 (Pavement Perspective on AV Safety through Optimizing Lateral Positioning Pattern)
- 02-009 (Vehicle Occupants and Driver Behavior: An Assessment of Vulnerable User Groups)
- TTI-01-03 (Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps)
- TTI-Student-05 (Exploring Crowdsourced Monitoring Data for Safety)

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.

[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.

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 04-104 (Development of a Connected Smart Vest for Improved Roadside Work Zone Safety) conducted presentations of research results to the Virginia Asphalt Association, Myers-Lawson School of Construction Advisory board and Honors' college advisory board (Boeing, GE, Caterpillar).
- Project VTTI-00-022 (Automated Truck Mounted Attenuator) hosted a design workshop to showcase their research results.
- TTI-01-05 (K-12 STEM Program: Exploring the Science of Retroreflectivity) hosted an informative workshop at the Science Teachers Association of Texas in Dallas.
- Safe-D study VTTI-00-026 (Guiding Driver Responses During Manual Takeovers from Automated Vehicles) conducted a meeting to review their plan for the remainder of the projects duration and performed a demonstration of the working human-machine interface prototypes to the industry champion.
- Safe-D student researchers presented project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway), at the SDSU 2020 Student Research Symposium.

Professional Skills Training Series

Safe-D/CARTEEH Graduate Student Leadership Development Seminar

The Safe-D National UTC and Center for Advancing Research in Transportation, Emissions, Energy, and Health (CARTEEH) hosted a seminar titled “Preparing an Effective Conference Poster” on November 25, 2019. This seminar was hosted by graphics designers Mary Beth Kegley and Stacy Schnettler from VTTI and TTI respectively. They used their experience and expertise to educate students on creating visually appealing and informative posters for use at future conferences.

CARTEEH hosted TTI Director Greg Winfree to speak about developing effective leadership skills on February 3, 2020. Prior to serving as director of TTI, Winfree held the position of Assistant Secretary at the United States Department of Transportation (USDOT). He also served as Corporate Counsel for several Fortune 500 companies prior to his USDOT appointment. Winfree’s years of experience brought a great perspective to what it means to be an effective leader and his presence was beneficial to the Graduate Students.

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 Lifesavers Traffic Safety Scholar

The 38th annual Lifesavers National Conference on Highway Safety Priorities took place in Tampa, Florida on March 15-17, 2020. Soheil Sohrabi, a Texas A&M Safe-D student, was selected as a Traffic Safety Scholar. The Traffic Safety Scholars Program provides up to $1,000 for 50 students to attend the conference every year.

Safe-D Student Wins Awards for Best Student Paper at Annual HFES Meeting

Alex Noble, a Virginia Tech Safe-D student, won the prestigious Alphonse Chapanis Best student paper award at the 63rd Annual Human Factors and Ergonomics Society Meeting on Nov 1, 2019, in Seattle, WA. Noble also received the award for best paper from the Surface Transportation Technical Group, which operates within the Human Factors and Ergonomics Society. Noble won these two awards for her research paper titled *Driver Training for Automated Vehicle Technology – Knowledge, Behaviors, and Perceived Familiarity*.

Safe-D Student Named 2019 Outstanding Student of the Year

Noble was also named the 2019 Outstanding Student of the Year for her numerous contributions during the past year at the Council of University Transportation Centers Annual Awards Banquet held on January 11, 2020, in Washington, DC. The event celebrated the outstanding students and faculty who have contributed to transportation research and education. The event drew more than 300 distinguished individuals from academia, the transportation industry, and the government.

Safe-D Student Named 2020 ISE Outstanding Doctoral Student

In addition, Noble was named the 2020 Virginia Tech Department of Industrial Systems Engineering Outstanding Doctoral Student of the Year. Noble earned this award for her extensive research at VTTI and her contributions to numerous publications and scientific articles.

Additional Student Awards

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

- Marcus Brewer and Jayson Stibbe received Best Paper Award from the Transportation Research Board Committee on Geometric Design at the 2019 Annual Meeting.
- Gregory Beale received the prestigious Liviu Librescu Memorial Fellowship award.
- Soheil Sohrabi was recognized as a 2020 Traffic Safety Scholar at the 38th annual Lifesavers conference. Sohrabi also received the 2019 Texas ITS Scholarship.
- Anagha Katthe received multiple Research Awards for Diversity, Inclusion and Social Justice
- Vamsi Vegamoor was awarded the Dwight Eisenhower Fellowship.

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 22 graduate and 16 undergraduate courses, reaching 309 graduate and 595 undergraduate students. Safe-D research projects supported 44 undergraduate- and graduate-level students during this reporting period, including 12 students from underrepresented populations. In addition, research teams reported that one student who graduating during the course of research activities continued on to pursue higher education. 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	9	1
Masters	9	3
PhD	26	8

Highlighted EWD & Other Outreach Activities

15th Annual VDOT Career Fair

The VDOT [Virginia Department of Transportation] Career fair, hosted in Manassas VA, was attended by roughly 1,300 high school students interested in transportation related careers. Safe-D Researchers Gregory Beale and Eileen Herbers (VTTI) showcased information about the Safe-D National UTC fund and careers in transportation research. Organizations from across VTTI brought the Tesla Model X to facilitate discussions with students about the possibilities for the future of automated transportation systems. This helped drive interest in the Institute and especially the research being done within.

Safe-D Student and Faculty Interview Chain

In this reporting period, Safe-D students and researchers started a networking and interviewing chain to help Safe-D students generate better connections with fellow students and professionals in their field of study. This chain provides more opportunities for research and has the potential to increase employment and partnering opportunities for students.

USDOT'S Accessibility and Mobility for All Summit

Safe-D researchers traveled to the USDOT's Mobility for All Summit on October 29, 2019, in Washington, DC. Researchers Charlie Klauer and Zac Doerzaph from VTTI gave presentations on driver training for AV technology at the innovation showcase. The project showcased the impacts of ADAS training tailored to specific demographics. The summit provided a good opportunity for outreach and information exchange with government and other private organizations.

Virginia Tech Science Fair

On November 16, 2019, Safe-D students Gregory Beale and Nicholas Britten (VT/VTTI), took part in the Virginia Tech Science fair in Blacksburg, Virginia. This event was attended by nearly 6,000 students, teachers, and parents from the local area. VTTI setup two separate exhibits for the students to showcase their research. The first exhibit featured an autonomous RC car equipped with a lidar sensor. Attendees were able to see how the vehicle autonomously navigated its environment and how the software interfaced with the vehicle. The second exhibit showcased how VTTI instruments and captures research data on full scale test vehicles. The science fair was a great opportunity to drive student engagement with VTTI and gain exposure to the local community as well.

International Scholar Óscar Mata

VTTI and Safe-D researchers hosted International Scholar Óscar Mata from the from the University of the Basque Country - Digital Electronics Design Group on Thursday, January 30, 2020. Óscar Mata's group, the Digital Electronics Design Group, has been working on developing ADAS for the past 20 years. Mata's research utilizes computational intelligence algorithms and hardware design to minimize cost and power consumption for ADAS.

Safe-D Webinar Series

Older Drivers and Transportation Network Companies: Investigating Opportunities for Increased Safety and Improved Mobility

The Safe-D webinar series hosted Dr. Melissa Tooley from TTI to discuss her research with older drivers and transportation network companies took place on January 23, 2020. The project investigated the potential for transportation network companies (TNCs; e.g., Uber and Lyft) to improve the mobility and safety of adults aged 65 to 85. Many adults of this age group experience a decline in driving ability, putting at them at greater risk for serious injury. The focus was on the perceptions toward, and ability of, this age group to use TNC smartphone applications. Tooley showcased the outreach and educational materials for older adults that were developed as a result of the research project.

Model Selection Heuristics Based on Characteristics of Data & Rare Events Modeling

This Safe-D webinar series hosted a two-part discussion featuring Ali Shirazi from Texas A&M University and Feng Guo from VTTI. Part one of the webinar discussed the importance of selecting the proper evaluation model based on the characteristics of the data being evaluated. The presenters proposed the use of Monte-Carlo Simulations and Machine Learning Classifiers to predict the "most likely true" distribution for analyzing data. Part two of the webinar focused on Rare Event Modeling, developing a bias adjustment for more accurate estimation of the safety impact of a risk factor and developing decision-adjusted framework to optimize predictive performance based on the objective of the study.

Street Noise Relationship to Vulnerable Road User Safety

This Safe-D webinar series was hosted by Greg Griffin from Texas A&M University on February 12, 2020. The study being showcased evaluated the impact of street noise on bicycle crash rates in Austin, TX and Washington, DC. The project collected a variety of street noise in both cities, over a wide range of locations and facility types,

and compared these against bicycle crash records, normalized against a number of variables. Modeling explained 87% of the variation in crash risk in the Washington, DC route.

Pavement Perspective on Automated Vehicle Safety Through Optimized Lateral Positioning Pattern

This Safe-D webinar series was hosted by Fujie Zhou from TTI on February 18, 2020, to discuss issues related to the effects of AVs on pavement conditions. His study found that AVs wander laterally in their lane three times less than regular human operated vehicles. This smaller lateral wandering shortens pavement fatigue by 22% but increases pavement rut depth by 30%. The result of the increased rut depth puts AVs at a significantly higher risk of hydroplaning. To reduce this risk, the study recommended applying a wandering pattern with uniform distribution to AVs. Adding this uniform wandering pattern reduces the potential of hydroplaning while increasing the overall life of the pavement.

Analysis of an Incentive-based Smart Phone App for Young Drivers

This Safe-D webinar series was hosted by Russell Henk from TTI on February 25, 2020. The discussion was based around TTI's development of an incentive-based smart phone app to help reduce the number of traffic incidents due to distracted driving. In two separate studies, two versions of the app were used, with 12,200 trips and more than 100,000 miles driven. The results showed that there was a significant reduction in distracted driving due to the incentive-based application.

Safe-D Researcher Honors and Awards

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

- Nazila Roofigari-Esfahan was recognized by Governor Northam for receiving the Commonwealth of Virginia research commercialization award.
- Atsushi Nara was awarded The Michael Breheny Prize for the Best Paper in Environment and Planning B: Urban Analytics and City Science.
- Tony McDonald won the Human Factors Prize for Excellence in Human Factors Research.
- Christopher P. Paolini was granted a Research Fellowship at Lawrence Berkeley National Laboratory for Summer 2020.
- Sivakumar Rathinam was honored as an The Institute of Electrical and Electronics Engineers Senior Member and received the Office of Naval Research Summer Senior Faculty Fellowship.

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 been impacted significantly by COVID-19. Many EWD outreach activities and T2 demonstrations that were planned for the April–September 2020 period have either been cancelled or postponed, making our goals in these areas difficult to achieve. For example, Safe-D was scheduled to attend the 2020 USA Science & Engineering Festival on April 24–26, 2020, in Washington, DC and had created an outreach activity led by Safe-D student researchers for event attendees; however, in the weeks prior to this 300,000+ attendee event, it was announced that the event would be postponed and no new date has been announced as of yet. Safe-D is planning to attend and present at this event once a new date is announced. Safe-D was also planning to support the Women in Transportation (WTS) Event, led by the VT WTS chapter, on March 27, 2020. The university

subsequently canceled all events in the wake of COVID-19 impacts, including this event. The impacts of COVID-19 on Safe-D research are described in detail in the Impact of COVID-19 section of this report.

Safe-D has confirmed that some EWD and T2 activities will still be able to take place during the next reporting period, with some modifications. These activities are described in the following sections.

2020 Undergraduate Research Internship Program

Safe-D will once again host a summer undergraduate research internship program at Texas A&M University in College Station, Texas. The program offers students the opportunity to participate in research in the areas of connected vehicles, AV, big data analytics, and transportation as a service. Each student will be paired with a research mentor and will work on an ongoing research project. Due to the impact of COVID-19 on student activities and human subjects research, TTI has altered the structure of the internship program so that internships can be completed remotely. Two of the selected students had been paired with research projects whose research activities cannot be completed remotely; therefore, unfortunately, these two student internships were cancelled.

Safe-D Webinar Series

The Safe-D Leadership Team is currently planning to conduct webinars to disseminate research project results to a broad audience during the next reporting period. It is expected that Safe-D will conduct at least one webinar per month moving forward; notifications of upcoming webinars will be posted on the Safe-D website and sent to the Office of the Assistant Secretary for Research and Technology for posting to their list as well.

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

- Safe-D project TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity) members collaborated with North Central Texas Council of Governments in Dallas, Texas and University of Texas Center for Transportation Research in Austin, Texas.
- TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity) members collaborated with CARTEEH in Bryan, Tx on project activities.
- Safe-D project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) members partnered with Ford and Spin to received financial support.
- Project 04-113 (Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements) members collaborated with VDOT to provided data collection support.
- VTTI-00-026 (Guiding Driver Responses During Manual Takeovers from Automated Vehicles) project members collaborated with GM in providing cost-share funding and contributing to this project as an industry champion
- Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) members collaborated with Linscott Law, Greenspan Engineers, and Caltrans to provide in-kind support for this project.
- TTI-Student-05 (Exploring Crowdsourced Monitoring Data for Safety) and their project team collaborated with partners at StreetLight Data, Iteris, INRIX, and Miovision to provide supporting data.

- Project VTTI-00-027 (An Evaluation of Road User Interactions with Automated Shuttles) members worked with State Farm to fund two projects, guidance on research questions, and feedback on scenario development.
- Safe-D project 04-115 (Reference Machine Vision for ADAS Functions) members created a partnership with 3M to provide materials for testing and useful suggestions to research.
- Project 04-117 (A Sensor Fusion and Localization System for Improving Vehicle Safety In Challenging Weather Conditions) members assisted TAMU Mays Innovation Center in College Station, Texas to provide Financial support for Vamsi Vegamoor (graduate student).

International Collaborators

- Safe-D project 04-114 (Behavior-based Predictive Safety Analytics Phase II) members partnered with Technical University of Braunschweig in Germany for in-kind collaborative research.
- Safe-D project 03-036 (Modeling Driver Responses during AV Platooning Failures) members partnered with Leeds University UK for collaborative research
- 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 2,729 visitors during the 6-month reporting period. With the 1,550 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 4,279 visitors between April 1, 2019 and March 31, 2020. Project Page visits averaged just over 40 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 number of Project Page visits for the prior two 6-month periods was 49.8 and 42.5, 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	2,729; 4,279 visitors/previous 12 mo.
	Project Pages: Average ≥ 150 visitors/year	2,357 total visits/period; average 40 visitors/project page
Journal Articles/Conference Presentations	Project Teams: 1 article/year	8 articles; 0.26 average per reporting project
	Project Teams: 1 conference/year	3 presentations; 0.097 average per reporting project
Facility Tours	Displays viewed by ≥ 200/year	5,886 total visitor views; average of 190 views per reporting project
	Follow-up Interest: 5 visitors/year	4

Prior to this reporting period, a total of 21 projects had been completed, resulting in 34 journal articles and 84 conference presentations. Within this reporting period, five additional projects were completed and a total of eight

new journal articles with three 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 3.3 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 5,886 views of Safe-D displays during outreach events during the 6-month reporting period; last period, researchers reported 850 views, bringing the yearly total to 6,736, which greatly exceeds with the annual goal of 200 views. The Safe-D team believes the significant increase in display views being reported here is likely a result of more accurate accounting and reporting of this metric as compared to prior reporting periods.

Publications, Conference Papers, and Presentations

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

Journal Publications/Conference Papers

Alambeigi, H., McDonald, A.D., and Tankasala, R. (2020). Crash themes in automated vehicles: A topic modeling analysis of the California Department of Motor Vehicles Automated Vehicle Crash Database. Presented at the 99th Annual Meeting of the Transportation Research Board. Washington, D.C. January 2020. (Accepted)

Alambeigi, H. & McDonald, A.D. (2020). Modeling post-takeover avoidance and stabilization steering control in automated vehicles. Submitted to the Annual meeting of the HFES. (Submitted)

Jefferson, J. A. and McDonald, A.D. (2019). The automated vehicle social network: Analyzing tweets after a recent Tesla Autopilot crash. To be presented at the Human Factors and Ergonomics Society's 2019 International Annual Meeting, Seattle, WA, October 2019. (Accepted)

Lee, K., & Sener, I. N. (2020). Emerging data for pedestrian and bicycle monitoring: Sources and applications. Transportation Research Interdisciplinary Perspectives, 100095. (Published)

Liang, D., Lau, N., Baker, S., and Antin, J. Examining Senior Drivers' Attitudes Towards Advanced Driver Assistance Systems after Naturalistic Exposure. Innovation in Aging (In review, IA-2019-265). (Accepted)

Marks, C., Jahangiri, A., & Machiani, S. G. (2019, October). Identifying and Labeling Risky Driving: A Multi-Stage Process Using Real World Driving Data. IEEE Transactions on Intelligent Transportation Systems. (Submitted)

Marks, C., Jahangiri, A., & Machiani, S. G. (2019, October). Iterative DBSCAN (I-DBSCAN) to Identify Aggressive Driving Behaviors within Unlabeled Real-World Driving Data. In 2019 IEEE Intelligent Transportation Systems Conference (ITSC) (pp. 2324-2329). IEEE. (Published)

Wei, R., Alambeigi, H., McDonald, A.D. (2020) Topic modeling social media data after fatal automated vehicle crashes. Submitted to the HFES Annual Meeting. (Submitted)

Presentations

Antin, Jonathan F., Ph.D. (2019. December). Comparing Senior Driver Mobility & Driving Performance with and without ADAS using Naturalistic Driving Data. Presentation to Oversight Committee for Use and Oversight of SHRP 2 Safety Data, Phase 1. Safety Data Oversight Committee (SDOC). Washington, D.C. (Accepted)

Cordova, E. (2020, Feb). Preliminary Development of the Risky Driving Index (RDI), 13th Annual Student Research Symposium, San Diego State University, Feb. 28-29, 2020. (Poster). (Accepted)

Katthe, A., Ghanipoor Machiani, S., & Jahangiri, A. (2020, Feb 28). Safety Impact Evaluation an Automated Vehicle Exclusive Lane on I-15; Crash Data Analysis. Presented at SDSU Student Research Symposium (SRS). (Accepted)

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 344 users per month, with 1,996 new users during this period. Users viewed pages 2,253 times during this period, visiting an average of 2.14 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 310 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, the Safe-D leadership team 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 create outcomes resulting in changes to the transportation system through increased understanding and awareness of transportation issues; focus and impact on future policy, regulation, rulemaking, and legislation; additions to the body of knowledge; training of the future transportation workforce; and improvements to 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 see Safe-D projects which are resulting in the adoption of new technologies, techniques, or practices as outlined in the next sections.

The T2 Performance Goals and corresponding Metrics for Outcomes/Impacts, as written in the currently approved Safe-D T2 Plan, are listed below (Table 3). Particularly noteworthy, Safe-D project teams participated in thirteen outreach events to promote the program and projects to an audience totaling 764 practitioners, including DOT officials, industry partners, and transportation researchers. This outreach exceeded our annual goals in this area and demonstrates the broad extent of the Safe-D program. Within this reporting period, Safe-D researchers did not report any DOTs adopting technologies resulting from projects. As this is a continuing trend that we have seen in previous periods, we do foresee any changes in the next reporting period as follow-on funding is expected from our partnering infrastructure owner-operators instead. Perhaps not well represented within these data, the Safe-D T2 Plan solicits direct input from stakeholders by requiring most project teams interact with a project champion from an industry partner. The industry champion involvement helps steer the research teams towards delivering project products that better match real industry needs. The goal of this requirement was to increase the likelihood of adoption and utilization of research results and we believe it is working. However, it is difficult to gain visibility into how industry is using the research outcomes and thus we believe the metrics are underreported. As with the prior reporting period, it is also our assumption that few of the projects that went through the new process have reached a point in their timelines where deliverables would be mature enough for implementation. To improve reporting, the Safe-D team will reach out to the industry champions directly to request implementation information prior to the next period. In general, Safe-D expects that practitioner use of technology will increase with maturity and closer to the end of the program. In general, the Safe-D program is currently on-track to meet its T2 performance goals; albeit with bolstering of the implementation metrics.

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	13 events, 0.42 average events per reporting project
	Each Event: average 15 practitioners	764 total attendees; average of 59 attendees/event
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	0
	Follow-on funding from 2 DOTs	0

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. For example,

- Project 03-049 (Data Fusion for Non-Motorized Safety Analysis) has increased our understanding of bicycle travel demand modeling, the use of crowdsourced data sources for non-motorized travel data, and non-motorized travel sources.
- Project 04-104 (Development of a Connected Smart Vest for Improved Roadside Work Zone Safety) has drawn awareness to work zone safety through the development of a technology to reduce the risks faced by work zone workers.
- Project TTI-04-02 (Delving into Safety Considerations of E Scooters: A Case Study of Austin, Texas) has led to increased understanding and awareness of e-scooter safety considerations, including within the medical field.
- Project TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity) has greatly enhanced understanding and awareness of the importance of how autonomous vehicles affect public health.

Passage of New Policies, Regulation, Rulemaking, or Legislation

During this reporting period, Project 03-036 (Modeling Driver Responses during AV Platooning Failures) directly affected public policy. One of the outputs of this study was an analysis of the California Department of Motor Vehicles (CDMV) crash database. This analysis led representatives from the CDMV to contact the research team to discuss ways to improve the crash database. The discussed improvement will be implemented in the near future.

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, based on the findings of Project 04-103 (Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: Phase II), the research team submitted a journal article for publication that focuses on seniors' acceptance of and adaptation to ADAS and the factors that influence their perceptions of such systems. These findings lay an important foundation for future research in this arena. In addition, the primary investigator has secured funding from the National Highway Traffic Safety Administration for a collaborative study that will build directly on this Safe-D project. This project also generated valuable information regarding the essential role of user documentation and adequate training on ADAS; these findings provide important insights for industry stakeholders as they seek to meet the needs of consumers. Similarly, Safe-D project 03-036 (Modeling Driver Responses during AV Platooning Failures) produced a literature review that consolidated over 200 articles into a set of core findings regarding driver performance during AV takeovers. Since its publication, this review has been cited 18 times by

researchers throughout the world. Other examples of contributions to the body of knowledge can be found in the Impacts section below.

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

The outcomes of numerous Safe-D projects have been processes and technologies that can be applied to improve transportation safety. For example, under Project 04-104 (Development of a Connected Smart Vest for Improved Roadside Work Zone Safety), the research team developed a technology that can be used in work zones to reduce injuries and fatalities associated with work zones. Similarly, Safe-D project VTTI-00-022 (Automated Truck Mounted Attenuator) has developed an automated truck mounted attenuator (ATMA) system that removes drivers from the most vulnerable TMA position within dynamic and short-duration work zone operations. The key to developing an ATMA design that can be rapidly migrated into operational field trials is the design of a tight leader-follower configuration within the dynamic platoon configurations of work zone operations. By creating a system designed and customized for short following distances (50–400 feet), this project has reduced some of the complexity of the operational control, object detection, potential for the incursion, and potential for communications loss. The design also includes a robust user interface that allows the lead vehicle driver to monitor and maintain situational awareness regarding the following vehicle behavior. The developed ATMA can be tested in real work zone operations.

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. Examples of this include the following:

- Project TTI-01-03 (Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps) has shown how researchers and practitioners can apply data from the SHRP 2 NDS dataset to the design of freeway ramps.
- The outputs of project VTTI-00-021 (Signal Awareness Applications) have enhanced the current capabilities of the Virginia Connected Corridors (VCC) platforms by developing new signal awareness safety and mobility features.
- Project 03-087 (Big Data Visualization and Spatiotemporal Modeling of Aggressive Driving) developed an interactive web-based tool that identifies when and where risky driving has occurred in the road network. This tool can be applied by agencies to identify potential risky locations and implement appropriate countermeasures to reduce risky driving behavior.
- The innovative crowdsourcing methodologies developed and validated under project TTI-Student-05 (Exploring Crowdsourced Monitoring Data for Safety) are now available for adoption by practitioners.
- One output of project 03-036 (Modeling Driver Responses during AV Platooning Failures) are models of driver evasive maneuver decision making and post-takeover braking and steering control. These models are currently in the final stages of refinement. Once finalized, they may be used by AV technology stakeholders to calibrate design parameters within human limitations.
- Project VTTI-00-028 (Driving Risk Assessment Based on High-frequency, High-resolution Telematics Data) has developed Convolutional Neural Network–Long-Short-Term Memory (CNN-LSTM) methodology that can be used to model high-frequency telematics data.
- The Skateboarder and Pedestrian Dataset generated under project 04-110 (Developing an Intelligent TMC with a Safety Evaluation Focus for Smart Cities) can be applied to train and test machine vision models for detecting and classifying skateboarders and pedestrians. In turn, this will contribute to vision-based safety monitoring systems along with the development of other object detection and tracking models.

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 technology created as part of Project 04-104 (Development of a Connected Smart Vest for Improved Roadside Work Zone Safety) is expected to significantly improve worker safety in roadway work zones and reduce the rate of accidents in the transportation network near work zones, thereby reducing delays and injuries/fatalities. The outcomes of Project VTTI-00-022 (Automated Truck Mounted Attenuator) will remove vulnerable roadside workers from danger, enhancing safety for both on-site construction workers and workers within vehicles. Other Safe-D projects are affecting transportation effectiveness, or are expected to in the near future, through the provisions of new tools and methodologies or the generation of new data/information, as summarized below.

Provision of tools/methodologies for practitioners

During this reporting period, Safe-D projects have provided new tools and methodologies that can be applied by practitioners to enhance the effectiveness of the nation's transportation system. Some examples are provided as follows:

- Project TTI-01-03 (Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps) has provided a new method for estimating speed on freeway ramps that should allow new ramps to be designed based on more accurate information about driver acceleration and merging behavior.
- Project 03-049 (Data Fusion for Non-Motorized Safety Analysis) generated a new tool for estimating bicycle exposure that can be used to facilitate the design of effective and safe bicycle transportation systems.
- The results of Project 03-087 (Big Data Visualization and Spatiotemporal Modeling of Aggressive Driving) demonstrated how kinematic data (from sources such as connected vehicles or smartphones) within large datasets can be utilized to identify risky driving behavior, thereby helping practitioners identify risky driving and develop appropriate countermeasures.
- Project 01-003 (Data Mining to Improve Planning for Pedestrian and Bicyclist Safety) demonstrated how data from multiple sources (i.e., automated counting systems, video cameras, and crash data) can be combined to estimate pedestrian and bicyclist exposure and risk at signalized intersections. The general procedure can be applied to other units of analysis and is expected to help practitioners prioritize facilities with the greatest need for safety improvements.
- The findings of Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) provide decision-makers with new tools for understanding the effects of e-scooters, which will help reduce roadway conflicts and improve safety.
- Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety) provides a new method for obtaining valuable information from Twitter that can be used to understand user perceptions and interactions with AVs.

Provision of information for better decision making

Other Safe-D projects have generated valuable new data and information that can implemented by decision-makers to improve the effectiveness and safety of the transportation system. For example, Project 04-103 (Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: Phase II) produced a robust understanding of the ways that senior drivers accept and use ADAS. This information will lead to a safer, more mobile cohort of senior drivers. Project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) provided information that fills a critical gap related to the behaviors of e-scooter users and their interactions with other vehicles and pedestrians with which they share the road. The findings can be used to identify policies, infrastructure,

technologies, and practices centered on e-scooter use that will improve the safety of all road users in mixed traffic. Ultimately, the outcomes of this project are expected to influence the transportation system by improving the safety of e-scooter riders along with pedestrians and enhancing the community acceptance of new transportation methods.

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 the Safe-D T2 Coordinator, Dr. Mike Mollenhauer. 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. The potential for commercialization and adoption of new practices resulting from several specific Safe-D projects are summarized below:

- Project TTI-01-03 (Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps) identified a previously unused source of data that can be used in a variety of design and operational studies. The results provide a new way of estimating speed on freeway ramps based on many vehicles at many locations.
- The results of Project 04-114 (Behavior-based Predictive Safety Analytics Phase II) are expected to influence how fleet management, insurance agencies, in-vehicle monitoring system vendors, and other parties use previously collected data to improve driver safety in real time based on the self-regulation of driving behaviors using active information garnered from vehicle data collection systems. The findings may also guide industry on the types of data that need to be collected to identify high-risk individuals. Finally, project findings may lead to an adjustment in the selection or retention procedures used by organizations to maintain a safe driver workforce.
- The findings of Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) are expected to change the way that future infrastructural elements are designed to accommodate the deployment of AVs.
- Project TTI-Student-05 (Exploring Crowdsourced Monitoring Data for Safety) validated crowdsourcing methods for obtaining bike and pedestrian data, which are expected to lead to new practices for collecting data from non-motorized road users.
- Under Project 04-115 (Reference Machine Vision for ADAS Functions), Safe-D researchers developed a reference lane departure system, providing a benchmark for evaluating the effectiveness of different lane markings and perception algorithms to reliably engage lane departure warning and lane keep assistance systems.

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. The impacts of specific Safe-D research projects on scientific knowledge in several important transportation fields are summarized below.

Data Analytics in Transportation

One important impact of Safe-D research has been the introduction of new types and sources of data along with new analytic strategies to leverage these data to improve transportation safety. For example, Project TTI-01-03 (Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps) developed a new methodology for estimating speed on freeway ramps based on many vehicles at many locations. This method improves upon the strategy typically used for speed estimation on ramps by incorporating information from a much broader sample of drivers. In Project 03-087 (Big Data Visualization and Spatiotemporal Modeling of Aggressive Driving), Safe-D researchers used both supervised and unsupervised learning algorithms to distinguish

risky driving events from normal driving events and applied a new approach to label risky driving. The developed approach, which combines supervised and unsupervised learning, can be adopted in other similar circumstances where it is difficult to label specific events required to train predictive models. Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety) developed a Twitter search algorithm that represents a significant step forward in mining Twitter data by combining keywords with a user crawling mechanism that finds tweets that are topically related to the keywords but do not contain them.

Automation

As one of the four key disruptive technologies targeted by Safe-D research, the body of scientific knowledge surrounding vehicle automation has been directly affected by center research. Examples of contributions to the field of automation during this reporting period include the following:

- The findings of Project VTTI-00-022 (Automated Truck Mounted Attenuator) provide valuable information on effective forms of internal and external communication that can be applied to other types of AVs. The leader-follower technology developed in this project also provides important insights for the future development of similar systems.
- Project TTI-Student-06 (Quantifying the Benefits and Harms of Connected and Automated Vehicle Technologies to Public Health and Equity) has contributed to the body of knowledge surrounding connected and automated vehicles by revealing their potential effects on (1) travel demand; (2) roadway safety; (3) air quality and disease burden; and (4) health and equity.
- Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) has begun to fill a critical gap in knowledge by providing foundational data to inform the future development of AV-compatible infrastructure.
- Project 03-036 (Modeling Driver Responses during AV Platooning Failures) has advanced the science of steering control models by providing a useful set of recommendations for the design of driver models, which have been used to study emotions and trust in AVs.
- The findings of Project 04-103 (Examining Senior Drivers' Adaptation to Mixed-Level Automated Vehicles: Phase II) provided guidance for refining adaptive cruise control algorithms based on data collected from senior drivers.

Pedestrian and Bicyclist Safety

Several Safe-D studies have yielded valuable results during this reporting period that advance the body of knowledge in the area of vulnerable road user safety. For example, Project 03-049 (Data Fusion for Non-Motorized Safety Analysis) developed different bicycle travel demand models based on different but complementary datasets. These models, along with the developed modeling and data analysis procedures, provide important contributions to the field of bicyclist safety. Project TTI-Student-05 (Exploring Crowdsourced Monitoring Data for Safety) validated several types of data crowdsourcing methods related to bike and pedestrian data, which has been a challenge in past decades. Under Project 01-003 (Data Mining to Improve Planning for Pedestrian and Bicyclist Safety), Safe-D researchers introduced a new method to quantify the risk associated with walking and bicycling at signalized intersections. This method utilizes a novel sampling strategy to develop a representative sample of intersections for data collection, which is expected to be applied in future studies on pedestrian and bicyclist safety.

Micromobility

Safe-D projects focused on the use of e-scooters as a micromobility solution have yielded important findings in this emergent field. Research on the safety impacts of e-scooter deployments are currently limited, and the ubiquity and ease of use of e-scooters has led to conflicts between e-scooters and other roadway users. Safe-D project VTTI-00-023 (E-Scooter Safety Assessment and Campus Deployment Planning) is increasing the body of knowledge and available data regarding e-scooter deployments and rider safety. The findings from this study will inform future decisions related to e-scooter deployment and help stakeholders understand the causes of these conflicts (e.g., confusion over formal or informal roadway rules, mistakes due to being a novice user, deliberate rule breaking, or other causes). The improved understanding of e-scooter conflicts resulting from this study will assist in the future

design of effective countermeasures for prevention or mitigation. Safe-D project TTI-04-02 (Delving into Safety Considerations of E-Scooters: A Case Study of Austin, Texas) is examining use and injury patterns of e-scooters in cooperation with county emergency medical services incident reports and emergency room records.

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 for Students of all Ages

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, Nicholas Britten, a graduate student working on project VTTI-00-024 (Characterizing Level 2 Automation in a Naturalistic Driving Fleet) participated in the Virginia Tech Science Festival in Blacksburg, VA, which targets K-12 students and was attended by approximately 6,000 students, parents, and teachers in November, 2019. His exhibit, which centered around an instrumented research vehicle, showcased the naturalistic driving methodology used by VTTI and aimed to inspire interest in transportation safety among the festival participants. Many Safe-D projects have also provided valuable hands-on experiences for undergraduate and graduate students, including the following:

- Project 03-049 (Data Fusion for Non-Motorized Safety Analysis) provided extensive opportunities for one graduate student to enhance their skills in advanced modeling and data analysis.
- Project VTTI-00-021 (Signal Awareness Applications) allowed a student to work on one of the most advanced vehicle-to-everything test bed deployments available in partnership with the VDOT and the Virginia Transportation Research Council.
- Project 03-087 (Big Data Visualization and Spatiotemporal Modeling of Aggressive Driving) allowed four students (two Ph.D. and two master's) to develop models to identify risky driving events from kinematic data; develop and design databases; and develop visualization tools.
- Project 04-113 (Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements) allowed students to learn how to assemble data, apply statistical techniques for data validation, and develop safety performance functions.
- As part of Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway), graduate research assistant Anagha Katthe presented a poster at the SDSU 2020 Student Research Symposium, for which she won the Research Award for Diversity, Inclusion and Social Justice. Students involved in this project have also become familiar with infrastructure design, safety considerations, traffic operations, and AV technology.
- Project 03-036 (Modeling Driver Responses during AV Platooning Failures) has provided first-time research experiences for eight undergraduate students and formed the basis for one student's Ph.D. dissertation focused on modeling driver behavior following automated vehicle takeovers. This Ph.D. student is from a traditionally underrepresented group in STEM.
- Two master's students, multiple undergraduates, and four Ph.D. students are currently engaged in Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety). With one exception, this project is the first exposure to transportation research for all of these students.
- Under Project 04-115 (Reference Machine Vision for ADAS Functions), one graduate student is working with fundamental vision processing algorithms and gaining valuable real-world experience by working

closely with industry partners to test the system. This work will also be part of the student's Ph.D. dissertation.

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:

- Project TTI-01-05 (K-12 STEM Program: Exploring the Science of Retroreflectivity) developed and disseminated new educational curriculum for K-12 teachers.
- The findings of Project 04-113 (Use of Disruptive Technologies to Support Safety Analysis and Meet New Federal Requirements) are being incorporated into a graduate course (CVEN 626, Highway Safety) at TAMU. The results of this study are also being incorporated into a textbook focused on highway safety.
- Project 03-036 (Modeling Driver Responses during AV Platooning Failures) generated a series of educational materials designed to teach driver behavior modeling to graduate students in engineering. These materials were used in a general decision-making course, representing the first exposure of most of the students in the course to driver modeling or transportation research.
- The data developed in Project 01-003 (Data Mining to Improve Planning for Pedestrian and Bicyclist Safety) were used to develop a group assignment for an undergraduate course (CIVE 160) at SDSU. This assignment allows students to develop statistical models to estimate pedestrian and bicyclist exposure based on real-world data.
- The methods and results stemming from Project VTTI-00-028 (Driving Risk Assessment Based on High-frequency, High-resolution Telematics Data) provide case-study examples for courses on multi-variate and statistical epidemiology.
- Project 04-098 (Data Mining Twitter to Improve Automated Vehicle Safety) generated a website designed to teach high school students how social media data can be used in transportation research.
- The methods for data collection, reduction, and analysis applied in Project VTTI-00-029 (Real-world Use of Automated Driving Systems and their Safety Consequences) were translated into a learning module entitled Naturalistic Driving Studies for Automated Driving Systems that highlights the opportunities and challenges of naturalistic driving studies for understanding the real-world use of driving automation. This learning module serves as a one-week class module for a graduate-level course (BME 5984, Advanced Vehicle Safety Systems), which is part of the Graduate Certificate in Human Factors of Transportation Safety program at Virginia Tech.

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. For example, industry partner LLG plans to present the findings of Project 04-101 (Safety Impact Evaluation of a Narrow Automated Vehicle-Exclusive Reversible Lane on an Existing Smart Freeway) at meetings of local transportation professional organizations such as the Institute of Transportation Engineers to educate transportation practitioners on the growing role of AVs and their integration into the mainstream transportation infrastructure. The best practices developed under VTTI-00-027 (An Evaluation of Road User Interactions with Automated Shuttles) will be incorporated into outreach for vocations including transit workers, emergency responders, and roadside and construction workers, whose duties will be affected by AVs. Project VTTI-00-022 (Automated Truck Mounted Attenuator) is expected to lead to changes in the nature of the transportation workforce; the automated system developed in this project is intended to replace the humans that currently operate TMAs manually, who are at a high risk of being injured if a TMA is struck on the roadway.

Changes/Problems

Changes in Approach

Nothing to report.

Actual/Anticipated Problems/Delays

Impact of COVID-19

During this reporting period, 22 Safe-D projects reported that research activities had been impacted by COVID-19 in some way. Among these projects, eight reported a minor impact, eight reported a moderate impact, and six reported a significant impact from COVID-19. Many of these impacts can be attributed to the social distancing measures and travel restrictions put in place in response to COVID-19. The responses of the consortium universities, which have all moved classes online and implemented hiring freezes, have also had repercussions for Safe-D projects. The specific ways in which COVID-19 has affected Safe-D research activities can generally be summarized as follows:

- Suspension of Safe-D research activities involving human subjects;
- Delays in collaboration between consortium institutions and corporate sponsors;
- Inability to hire needed staff due to freezes in university recruitment;
- Inability of Safe-D personnel to travel for field testing/demonstrations;
- Disruptions to factory outputs, the supply chain, and the workforce, preventing the manufacturing of project products;
- Suspension of e-scooter use on the campus of Virginia Tech;
- Large reduction of e-scooter use in Austin;
- Software/information technology issues resulting from remote work (e.g., slower network/computational speeds and the need to set up environments for data access and analysis);
- Temporary decreases in productivity resulting from the rapid transition to remote work and online instruction, including difficulty working remotely with disrupted students;
- Delays in instrumentation efforts due to restricted access to campus buildings/garages;
- Delays in data collection due to overall reduction in vehicular/pedestrian activity; and
- Delays or cancellations of EWD activities resulting from school closures.

Overall, the main outcome of the above effects of COVID-19 is expected to be delays to 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 will likely be needed 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 collection may be cancelled. For most projects, extensions are expected to be requested in the form of no-cost time extensions, although cost overruns are a possibility in some cases.

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