Program Progress Performance Report

Submitted to:	U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology
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Project Title:	Data-Supported Transportation Operations and Planning (D-STOP) Center
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Signature:	

1. ACCOMPLISHMENTS

What are the major goals of the program?

The Data-Supported Transportation Operations and Planning (D-STOP) Center's vision is to be a national and international multimodal and multidisciplinary center of excellence that promotes the integration of cutting-edge developments in wireless sensor networks and communications technology with transportation systems to improve the United States' economic competitiveness. This vision will be implemented through a research mission, an education and workforce development mission, and a technology transfer mission.

D-STOP's *research mission* is to develop fundamentally new methodologies to better harness traditional and recent data sources, and potentially develop new sources, in seeking to improve models for transportation planning and traffic operations. D-STOP research will occur in three areas: operations, planning, and technology, with significant priority placed on work that cuts across these areas.

The *education and workforce development (EWD) mission* is to build a transportation workforce that is able to use multi-disciplinary approaches to address multi-dimensional complex problems, through an emphasis on real-time data analysis and processing, the study of the dynamics underlying human activity-travel decision-making, and training on the effective use of information technology innovations.

D-STOP's *technology transfer (TT) mission* is to disseminate information on research activities and findings, and actively promote the utilization and implementation of research products/findings through demonstrations on small-scale networks (in collaboration with industry and public agency partners).

What was accomplished under these goals?

Research Program Accomplishments

D-STOP's research activities focus on harnessing innovative technologies and data sources to develop architectures and systems for data collection and analysis. The research will foster economic competitiveness through its focus on gathering and analyzing data to support effective and efficient decision-making. The major research accomplishment during this reporting period was the continued development of the research agenda in coordination with D-STOP faculty and researchers. A total of 21 projects were pursued with partial or full funding support from D-STOP. Of these, 3 projects were completed during this reporting period. Currently, 18 projects are underway, with 10 new projects approved by the Business Advisory Council.

Completed Projects

1. **Accommodating a Flexible Response Heterogeneity Distribution in Choice Models of Human Behavior for Transportation Planning**
   (PI: Chandra Bhat); End date: December 31, 2017

2. **Cybersecurity Challenges and Pathways in the Context of Connected Vehicle Systems**
   (PI: Chandra Bhat); End date: December 31, 2017

3. **Evaluation of Routing Protocols for Vehicular Ad hoc Networks (VANETs) in Connected Transportation Systems**
   (PI: Chandra Bhat); End date: December 31, 2017

Ongoing Projects

1. **Transportation Data Discovery Environment**
   (PI: Natalia Ruiz Juri); Anticipated end date: August 31, 2018

2. **Real-Time Signal Control and Traffic Stability**
   (PI: Stephen Boyles); Anticipated end date: August 31, 2018

3. **Using Collected Data to Improve Dynamic Traffic Assignment Modeling**
   (PI: Natalia Ruiz Juri); Anticipated end date: August 31, 2018

4. **Internet of Moving Things using Full Duplex Mesh Networks**
   (PI: Sriram Vishwanath); Anticipated end date: December 31, 2018

5. **Spatial Correlation Estimation of Millimeter Vehicular Communication Channels Using Out-of-Band Information**
   (PI: Robert Heath); Anticipated end date: May 31, 2018

6. **Joint Millimeter-Wave Communication and Radar for Automotive Applications**
   (PI: Robert Heath); Anticipated end date: May 31, 2018

7. **ADAS Enhanced by 5G Connectivity**
   (PI: Todd Humphreys); Anticipated end date: September 30, 2018

8. **Improved Models for Managed Lane Operations**
   (PI: Stephen Boyles); Anticipated end date: August 31, 2018

9. **Capturing the Impacts of Ride-sourcing and HOVs**
   (PI: Chandra Bhat); Anticipated end date: September 30, 2018

10. **V2I Managed Lanes Test Bed**
    (PI: James Kuhr); Anticipated end date: September 30, 2018

11. **Transition Period from Today to Fully Autonomous**
    (PI: Natalia Ruiz Juri); Anticipated end date: September 30, 2018

12. **Statistical Inference Using Stochastic Gradient Descent**
    (PI: Constantine Caramanis); Anticipated end date: August 31, 2018

13. **Clustering and Classification**
    (PI: Constantine Caramanis); Anticipated end date: August 31, 2018

14. **Bandit Algorithms for Online Learning and Resource Allocation**
    (PI: Sanjay Shakkottai); Anticipated end date: August 31, 2018

15. **V2X Spectrum Resource Allocation for Sensing and Communications**
    (PI: Sanjay Shakkottai); Anticipated end date: August 31, 2018

16. **New Microeconomic Theory-Based Model for Ranking Data**
    (PI: Chandra Bhat); Anticipated end date: September 30, 2018

17. **Megaregional Trends of Passenger and Freight Movement: Evidence from National Transportation Data Sources**
    (PI: Ming Zhang); Anticipated end date: September 30, 2018

18. **Transit Policy in the Context of New Transportation Paradigms**
    (PI: James Kuhr); Anticipated end date: September 30, 2018

Latest projects approved by the Business Advisory Council:

1. **Video Data Analytics for Safer and More Efficient Mobility**
   (PI: Natalia Ruiz Juri); Anticipated end date: September 30, 2020

2. **Data-Driven, Real-Time Traffic Signal Optimization: A Distributed Approach**
   (PI: Stephen Boyles); Anticipated end date: September 30, 2020

3. **Real-time, Targeted Incentives for Strategic Travelers**
   (PI: Stephen Boyles); Anticipated end date: September 30, 2020

4. **Tight-coupling of Vision, Radar, and Carrier-phase Differential GNSS for Robust All-weather Positioning**
   (PI: Todd Humphreys); Anticipated end date: September 30, 2020

5. **Modeling Willingness-to-Share Trips in an Autonomous Vehicle Future: A stochastic psychological latent construct approach**
   (PI: Chandra Bhat); Anticipated end date: September 30, 2020

6. **Emerging Transportation Mobility Options and Technologies: A comprehensive analysis of consumer preferences using survey and supplementary data**
   (PI: Chandra Bhat); Anticipated end date: September 30, 2020

7. **Sensing and Communications in V2V and V2I Settings**
   (PI: Sanjay Shakkottai); Anticipated end date: September 30, 2020

8. **Online Matching, Black-box Optimization and Hyper-parameter Tuning**
   (PI: Sanjay Shakkottai); Anticipated end date: September 30, 2020

9. **Solving Perception Challenges for Autonomous Vehicles Using SGD**
   (PI: Constantine Caramanis); Anticipated end date: September 30, 2020

10. **Large Scale Optimization with Small Scale Data**
    (PI: Constantine Caramanis); Anticipated end date: September 30, 2020

Research Results Disseminated: 15 papers were published and 15 papers are forthcoming in refereed journals based on the research projects associated with D-STOP. Several other papers are in the review process. 32 presentations were made at conferences and meetings.

Plans for Next Reporting Period to Accomplish Research Goal: Provide support, guidance, and assistance to project Principal Investigators so individual research project objectives can be achieved. Renew funding for supporting research through the North Central Texas Council of Governments (NCTCOG). Undertake supporting research funded through the Texas Department of Transportation and Cintra.

Education and Workforce Development Accomplishments

The research projects outlined above have several students working on them. Please note that students work in groups. Some are on fellowships, or obtain funding from other sources too. Below, we indicate all students who undertake research associated with D-STOP, regardless of whether they obtain no funding support or only partial funding support from D-STOP. The students are:

<u>Undergrad</u>

Justin Kinne, Daniel Guerrero, Aaron Logan, Andrea Vickers, Aarti Bhat, Gretchen Bella (supervised by Chandra Bhat)
Mark Stahl, Christine Cheng, Tejas Choudhary, Mathias Hanssen (supervised by Stephen Boyles)
Martin Vicente (supervised by Natalia Ruiz Juri)
Haoran Niu, Varun Prabhu, Jake Nimergood (supervised by Robert Heath)

<u>Grad</u>

Supervised by Chandra Bhat: Sebastian Astroza (PhD), Qichun Dai (MS), Felipe Dias (PhD), Joseph Hutchinson (MS), Patricia Lavieri (PhD), Kamryn Long (MS), Gopindra Nair (PhD), Abhilash Singh (MS), Pragun Vinayak (MS).
Supervised by Stephen Boyles: William Alexander (MS), Dongxu (Henry) He (MS), Rachel James (PhD), Venktesh Pandey (PhD), Rahul Patel (MS), Priyadarshan Patil (PhD), Prashanth Venkatraman (MS), Cesar Yahia (MS), Tengkuo Zhu (PhD).
Supervised by Natalia Ruiz Juri: Michael Dunn (MS), Natalia Zuniga (PhD).
Supervised by Ming Zhang: Caleb Roberts (MS).
Supervised by Constantine Caramanis: Eirini Asteri (PhD), Tianyang Li (PhD).

Supervised by Robert Heath: Anum Ali (PhD), Preeti Kumari (PhD), Khurram Mazher (PhD), Megha Parhi (MS), Vutha Va (PhD), Yuyang Wang (PhD), Ratbek Zhapparov (MS).
Supervised by Todd Humphreys: Daniel LaChapelle (PhD), Matthew Murrian (PhD), Lakshay Narula (MS/PhD).
Supervised by Sanjay Shakkottai: Soumya Basu (PhD).
Supervised by Joydeep Ghosh: Rahi Kalantari (PhD), Taewan Kim (PhD), Farzan Memarian (MS/PhD), Michael Motro (PhD).

The D-STOP Center selected MS student Rahul Patel (supervised by Dr. Stephen Boyles) as its 2017 Outstanding Student of the Year. MS student John Helsel (also supervised by Dr. Stephen Boyles) was awarded the Council of University Transportation Centers (CUTC) 2017 Charley V. Wootan Memorial Award for his MS thesis entitled “Getting to Work on Time: A Proposed Time-Equitable Tolling Scheme”. Rahul and John were recognized at an annual awards banquet in January 2018 in Washington DC before the TRB Annual Meeting.

Education and Workforce Development Results Disseminated:

Girl Day at UT Austin
D-STOP Graduate student members of the Institute of Transportation Engineers and Women's Transportation Seminar students groups gave an interactive demonstration to learn how to manage traffic signals and keep traffic flowing safely (Transportation: Getting You Where You Want to Go) during Girl Day on February 24, 2018. Participants tried to get all the traffic through an intersection accident free before time ran out. Girl Day at UT Austin is a free event for K-8 students (for both girls and boys) held on the Cockrell School of Engineering and Natural Sciences complexes at The University of Texas at Austin. Over 8,000 students participated in over 150 free-flowing hands-on activities and demonstrations hosted by volunteers, student organizations, corporate partners and community organizations. Students got the chance to explore engineering, science, math, and technology at their own pace throughout the event.

Prospective Grad Student Lunch: Dr. Stephen Boyles met with visiting prospective graduate students and current graduate students during a lunch meeting organized by the transportation graduate program on March 2, 2018. This session was designed to provide information to prospective graduate students of research currently being undertaken at UT-Austin, including under the D-STOP Center. The presentation also discussed ways to make the transition to graduate school easy, and the expectations of graduate school.

Explore UT
Robert Heath and his graduate students gave hands-on demonstrations of how antenna beam patterns change as a car moves in a millimeter wave vehicular communication system (Using the Millimeter Wave for 5G Wireless Communication and Beyond) and on navigation algorithms which use only on-board sensors to decide a trajectory and avoid obstacles during the flight of a UAV (Sensing and Navigation with Unmanned Aerial Vehicles (UAV)) at Explore UT on March 3, 2018. D-STOP Graduate students from the Center for Transportation Research also gave demonstrations on intelligent transportation systems, their use in the future, and to learn what and how a connected and autonomous vehicle “sees” (Creating a "Vision" for Connected and Autonomous Vehicles), and the Institute of Transportation Engineers and Women's Transportation Seminar students groups also gave an interactive session for participants to learn how to manage traffic signals and keep traffic flowing safely (Transportation: Getting You Where You Want to Go). Held annually at UT Austin, Explore UT aims to inform students, parents, teachers and community members from across the state about the importance of the public research institution and higher education in Texas. The day-long event invites

Texans of all ages to experience robust research experiences, hands-on demonstrations and experiments, and participate in the richness of the university's scholarship and knowledge.

Dr. Stephen Boyles was a guest lecturer to a freshman course at UT Austin with students from many different majors in March 2018. The lecture covered issues in transportation, including emerging technologies, land use, policy, intelligent transportation systems, and demand management.

Dr. Bhat is a member of the Engineering Advisory Board of Westwood High School and continues to advise the school on engineering curriculum issues.

Plans for Next Reporting Period to Accomplish Education and Workforce Development Goal:
Hold a joint meeting of the Business Advisory Council (BAC) and UT SAVES (Situation-Aware Vehicular Engineering Systems) board, planned for April 11, 2018. This will be the second board meeting of UT SAVES and the third BAC meeting. The University Transportation Center-Undergraduate Internship (UTC-UI) program will be held for a fifth year in the summer of 2018, and organization is underway. Each intern will participate in a research project related to the D-STOP center, and a weekly seminar will be held. Recruit and introduce a fresh batch of graduate students to D-STOP.

Technology Transfer Accomplishments
Technology transfer activities will be pursued to deliver timely information on research activities and findings. These activities include: maintaining a D-STOP website, producing high quality peer-reviewed journal papers, and supporting researcher travel to participate in conferences that disseminate research results.

D-STOP website: The D-STOP website provides information about the Center and includes a listing of current research projects being conducted, as well as educational information, technology transfer, news and events, publications, and resources applicable to the to the overall D-STOP effort. The website address is dstop.utexas.edu

2017 Texas Wireless Summit
The Texas Wireless Summit (TWS), hosted by the Wireless Networking and Communications Group (WNCG), was held November 6-7, 2017 at UT Austin. TWS brings together leading figures in industry, academia, and government to discuss the latest developments in information systems technology. The theme for this year, “What Started Here Has Changed the Wireless World,” was a celebration of the 15 years since the creation of WNCG, founded by Professor Ted Rappaport. Sessions and panels during the two-day summit explored cutting-edge developments in millimeter wave networks, the future of automated vision and navigation, software defined networking, theory and applications of machine learning and computation, and startups and entrepreneurship in the wireless space. The event also included a poster session, which allowed participants to take an inside look at current WNCG research projects. The Summit’s first session, titled “WNCG: The Last 15 Years and the Next 15,” focused on the history of the group. Panelists included current WNCG director Sanjay Shakkottai as well as all of the group’s previous directors: Robert Heath, Jeff Andrews, Gustavo de Veciana, and founding director Ted Rappaport. The Summit welcomed over 300 attendees to the newly opened Engineering Education and Research Center (EER) at The University of Texas at Austin. D-STOP’s Sanjay Shakkottai co-chaired this year’s event, which supported D-STOP’s technology transfer mission of disseminating information on research activities and findings, and actively promoting the utilization and implementation of research products/findings (in collaboration with industry and public agency partners).

USDOT Roundtable on Data for Automated Vehicle Safety
Dr. Chandra Bhat was invited to be a panelist at the U.S. Department of Transportation (U.S. DOT) Roundtable on Data for Automated Vehicle Safety on Thursday, December 7, 2017. Within and across all modes of transportation, data exchanges will be key to accelerating the safe deployment of automated vehicles (AVs) and other autonomous systems in the United States. During this all-day, invitation-only event, Dr. Bhat participated actively in discussions with colleagues from federal, state, and local government leadership and major industry stakeholders.

Publications: Papers whose research is fully or partially supported by D-STOP:

Published:

Jafari, E., and S. D. Boyles. "Online Charging and Routing of Electric Vehicles in Stochastic Time-Varying Networks." *Transportation Research Record: Journal of the Transportation Research Board*, 2667, 61-70, 2017.

Jafari, E., V. Pandey, and S.D. Boyles. "A Decomposition Approach to the Static Traffic Assignment Problem." *Transportation Research Part B,* 105, 270-296, 2017.

Levin, M.W., E. Jafari, R. Shah, and S.D. Boyles. "Network-based Model for Predicting the Effect of Fuel Price on Transit Ridership and Greenhouse Gas Emissions. *International Journal of Transportation Science and Technology*, 6(4), 272-286, 2017.

Sharon, G., M. W. Levin, J. P. Hanna, T. Rambha, S. D. Boyles, and P. Stone. "Network-Wide Adaptive Tolling for Connected and Automated Vehicles." *Transportation Research Part C* 84, 142-157, 2017.

Sharon, G., M. Albert, T. Rambha, S. Boyles, and P. Stone, "Traffic Optimization for a Mixture of Self-interested and Compliant Agents." Proceedings of the 32nd AAAI Conference on Artificial Intelligence (AAAI-18), New Orleans, Louisiana, February 2018.

Astroza, S., A.R. Pinjari, C.R. Bhat, and S.R. Jara-Diaz, "A Microeconomic Theory-Based Latent Class Multiple Discrete-Continuous Choice Model of Time Use and Goods Consumption." *Transportation Research Record: Journal of the Transportation Research Board*, 2664, 31-41, 2017.

Bhat, C.R., S. Astroza, and P.S. Lavieri, "A New Spatial and Flexible Multivariate Random-Coefficients Model for the Analysis of Pedestrian Injury Counts by Severity Level." *Analytic Methods in Accident Research*, 16, 1-22, 2017.

Dias, F.F., P.S. Lavieri, V.M. Garikapati, S. Astroza, R.M. Pendyala, and C.R. Bhat, "A Behavioral Choice Model of the Use of Car-Sharing and Ride-Sourcing Services," *Transportation*, *2017 TRB Annual Meeting Special Issue*, 44(6), 1307-1323, 2017.

Bhat, C.R., and P.S. Lavieri, "A New Mixed MNP Model Accommodating a Variety of Dependent Non-Normal Coefficient Distributions." *Theory and Decision*, 84(2), 239-275, 2018.

Huang, L., W. Xu, S. Liu, V. Pandey and N. R. Juri. "Enabling Versatile Analysis of Large Scale Traffic Video Data with Deep Learning and HiveQL." Proceedings of *2017 IEEE International Conference on Big Data (Big Data)*, Boston, MA, pp. 1153-1162, 2017.

Zhu, D., J. Choi and R.W. Heath, "Two-Dimensional AoD and AoA Acquisition for Wideband Millimeter-Wave Systems With Dual-Polarized MIMO." *IEEE Transactions on Wireless Communications*, 16(12), 7890-7905, December 2017. doi: 10.1109/TWC.2017.2754369

González-Prelcic, N., A. Ali, V. Va, and R.W. Heath Jr., "Millimeter-Wave Communication with Out-of-Band Information." *IEEE Communications Magazine*, 55(12), 140-146, December 2017. doi: 10.1109/MCOM.2017.1700207

Ali, A., N. González-Prelcic, and R.W. Heath Jr., "Millimeter Wave Beam-Selection Using Out-of-Band Spatial Information." *IEEE Transactions on Wireless Communications*, 17(2), 1038-1052, February 2018. doi: 10.1109/TWC.2017.2773532

Daniels, R.C., E.R. Yeh, and R.W. Heath Jr., "Forward Collision Vehicular Radar with IEEE 802.11: Feasibility Demonstration Through Measurements." *IEEE Transactions on Vehicular Technology*, 67(2), 1404-1416, February 2018. doi: 10.1109/TVT.2017.2758581

Chen, Y., X. Yi and C. Caramanis, "Convex and Nonconvex Formulations for Mixed Regression With Two Components: Minimax Optimal Rates." *IEEE Transactions on Information Theory*, 64(3), 1738-1766, March 2018. doi: 10.1109/TIT.2017.2773474

Forthcoming:

Pandey, V. and Ruiz Juri, N. "Using National Performance Management Research Data Set (NPMRDS) for Corridor Performance Measures: A US-281 N Corridor Case Study." *Transportation Research Record: Journal of the Transportation Research Board*, forthcoming, 2018.

Bansal, P., R. Shah, and S.D. Boyles. Robust Network Pricing and System Optimization under Combined Long-term Stochasticity and Elasticity of Travel Demand. *Transportation*, forthcoming, 2018.

Bhat, C.R., "A New Flexible Multiple Discrete-Continuous Extreme Value (MDCEV) Choice Model." *Transportation Research Part B*, forthcoming.

Bhat, C.R., "New Matrix-Based Methods for the Analytic Evaluation of the Multivariate Cumulative Normal Distribution Function." *Transportation Research Part B*, forthcoming.

Lavieri, P.S., F.F. Dias, N. Ruiz Juri, J. Kuhr, and C.R. Bhat, "A Model of Ridesourcing Demand Generation and Distribution." *Transportation Research Record*, forthcoming.

Nair, G.S., S. Astroza, C.R. Bhat, S. Khoeini and R.M. Pendyala, "An Application of a Rank Ordered Probit Modeling Approach to Understanding Level of Interest in Autonomous Vehicles." *Transportation*, 2018 TRB Annual Meeting Special Issue, forthcoming.

Singh, A.C., S. Astroza, V.M. Garikapati, R.M. Pendyala, C.R. Bhat, and P.L. Mokhtarian, "Quantifying the Relative Contribution of Factors to Household Vehicle Miles of Travel." *Transportation Research Part D*, forthcoming.

Va, V., J. Choi, T. Shimizu, G. Bansal, and R.W. Heath Jr., "Inverse Multipath Fingerprinting for Millimeter Wave V2I Beam Alignment." *IEEE Transactions on Vehicular Technology*, forthcoming. doi: 10.1109/TVT.2017.2787627

Kumari, P., J. Choi, N. González-Prelcic, and R.W. Heath Jr., "IEEE 802.11ad-based Radar: An Approach to Joint Vehicular Communication-Radar System." *IEEE Transactions on Vehicular Technology*, forthcoming. doi: 10.1109/TVT.2017.2774762

Rodriguez-Fernandez, J., N. González-Prelcic, K. Venugopal, and R.W. Heath Jr., "Frequency-domain Compressive Channel Estimation for Frequency-selective Hybrid mmWave MIMO Systems." *IEEE Transactions on Wireless Communications*, forthcoming. doi: 10.1109/TWC.2018.2804943

Va, V., J. Choi, T. Shimizu, G. Bansal and R.W. Heath Jr., "Impact of Measurement Noise on Millimeter Wave Beam Alignment Using Beam Subsets." *IEEE Wireless Communications Letters, forthcoming*. doi: 10.1109/LWC.2018.2825326

Eltayeb, M.E., T.Y. Al-Naffouri, and R.W. Heath Jr., "Compressive Sensing for Millimeter Wave Antenna Array Diagnosis." *IEEE Transactions on Communications*, forthcoming. doi: 10.1109/TCOMM.2018.2790403

Basu, S., A. Sundarrajan, J. Ghaderi, S. Shakkottai and R. Sitaraman, "Adaptive TTL-Based Caching for Content Delivery." *IEEE/ACM Transactions on Networking*, forthcoming. doi: 10.1109/TNET.2018.2818468

Meirom, E.A., C. Caramanis, S. Mannor, A. Orda, and S. Shakkottai, "Detecting Cascades from Weak Signatures." *IEEE Transactions on Network Science and Engineering*, forthcoming. doi: 10.1109/TNSE.2017.2764444

Wesson, K.D., J.N. Gross, T.E. Humphreys, and B. L. Evans, "GNSS Signal Authentication Via Power and Distortion Monitoring." *IEEE Transactions on Aerospace and Electronic Systems*, forthcoming. doi: 10.1109/TAES.2017.2765258

Submitted/under review:

Pandey, V., and S. D. Boyles. "Dynamic Pricing for Managed Lanes with Multiple Entrances and Exits." In review, *Transportation Research Part C*, 2018.

Sharon, G., P. Stone, and S. Boyles. "The Impact of Marginal Cost Pricing with a Fixed Error Factor on Traffic Networks." Submitted to International Joint Conference on Artificial Intelligence 2018.

Sharon, G., P. Stone, and S. Boyles. "Enhanced Delta-tolling: Traffic Optimization via Policy Gradient Reinforcement Learning." Submitted to International Joint Conference on Artificial Intelligence 2018.

Presentations whose research is fully or partially supported by D-STOP:

Presented:

Va, V., T. Shimizu, G. Bansal, and R.W. Heath Jr., "Position-aided millimeter wave V2I beam alignment: A learning-to-rank approach." *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Montreal, QC, October 2017, pp. 1-5.

Heath, R.W., "Millimeter Wave Communication with Out-of-Band Information." *Invited seminar*, Department of Electrical Engineering, University of Washington, Seattle, WA, October 2, 2017.

Heath, R.W., "Millimeter Wave MIMO Signal Processing." Keynote presentation, *International Conference on Wireless Communications and Signal Processing*, Nanjing, China, October 12, 2017.

Heath, R.W., "Millimeter Wave MIMO Signal Processing." Plenary presentation, *2018 Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, October 30, 2017.

Ali, A., "Millimeter Wave Spatial Covariance Estimation Using Out-of-Band Information." Poster presented at the *Texas Wireless Summit*, Austin, TX, November 7, 2017.

Kumari, P., "Adaptive IEEE 802.11ad Waveform Design for a Joint Automotive Communication-Radar System." Poster presented at the *Texas Wireless Summit*, Austin, TX, November 7, 2017.

Bhat, C.R., "Connected and Autonomous Vehicles: Where Are We Going and What Happens When We Get There?," *Invited Seminar*, Ferrovial Executive Forum, Madrid, Spain, November 2017.

Heath, R.W., "Millimeter Wave Communication Leveraging Out-of-Band Information." *Invited seminar*, Southern Methodist University, Dallas, TX, November 28, 2017.

Ruiz Juri, N., "Sharing Novel Transportation Data to Promote Innovation through Collaboration: Case Studies from Austin, TX." Presented at the *Visualizing Transportation Big Data for Efficient Decision Making Workshop*, Transportation Institute, University of Florida, Gainesville, FL, December 2018.

Boyles, S., "Parking Search Equilibrium and its Implications for Parking Management." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Buini, H.M., G. Sharon, St. Boyles, T. Givargis and P. Stone, "Enhanced Delta-tolling: Traffic Optimization via Policy Gradient Reinforcement Learning." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Sharon, G., M. Albert, T. Rambha, S. Boyles, and P. Stone, "Traffic Optimization for a Mixture of Self-interested and Compliant Agents." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Boyles, S., C. Xie, and X. Wu, "Path-Constrained Traffic Assignment: Continuously Distributed Bounds on Travel Weights." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., and S. Boyles, "Dynamic Pricing for Managed Lanes with Multiple Entrances and Exits." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., C. Yahia, S. Boyles, and J. Li, "Evaluation of Active Traffic Management (ATM) Strategies under Recurring and Non-recurring Congestion: an IH-35 Corridor Case Study." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Yahia, C., V. Pandey, and S. Boyles, "Network Partitioning Algorithms for Solving the Traffic Assignment Problem Using a Decomposition Approach." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V. and N. Ruiz Juri, "Using National Performance Management Research Data Set (NPMRDS) for Corridor Performance Measures: A US-281 N Corridor Case Study." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., W. Xu, L. Huang, S. Liu, and N. Ruiz Juri, "Processing large-scale video data to support transportation safety, planning, and operations: a flexible approach to data storage and integration." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Astroza, S., P.C. Bhat, C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Understanding Activity Engagement Across Weekdays and Weekend Days: A Multivariate Multiple Discrete-Continuous Modeling Approach," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Astroza, S., V.M. Garikapati, R.M. Pendyala, C.R. Bhat, and P.L. Mokhtarian, "Representing Heterogeneity in Structural Relationships Among Multiple Choice Variables Using a Latent Segmentation Approach," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Bhat, C.R., New Matrix-Based Methods for the Analytic Evaluation of the Multivariate Cumulative Normal Distribution Function *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Bhat, C.R., S. Astroza, and P.S. Lavieri, "A Model for the Analysis of Pedestrian Injury Counts by Severity Level," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Dai, Q., P.S. Lavieri, and C.R. Bhat, "Using Virtual Accessibility and Physical Accessibility as Joint Predictors of Activity-Travel Behavior," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Dias, F.F., S. Astroza, V.M. Garikapati, R.M. Pendyala, C.R. Bhat, and P.L. Mokhtarian, "A Multivariate Exploration of Emotional Feelings of Subjective Well-Being During Travel Episodes," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Lavieri, P.S., F.F. Dias, N. Ruiz Juri, J. Kuhr, and C.R. Bhat, "A Model of Ridesourcing Demand Generation and Distribution," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

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Sharon, G., M. Albert, T. Rambha, S. Boyles, and P. Stone, "Traffic Optimization for a Mixture of Self-interested and Compliant Agents." Presented at the *32nd AAAI Conference on Artificial Intelligence (AAAI-18)*, New Orleans, Louisiana, February 2018.

Heath, R.W., "Millimeter Wave MIMO Signal Processing." Plenary presentation, *2018 Workshop on Information Theory and Applications*, San Diego, CA, February 12, 2018.

Bhat, C.R., "A Joint Model of Virtual and In-Person Out-of-Home Activity Engagements," *Invited Seminar*, Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University (PolyU), jointly organized with the Hong Kong Society for Transportation Studies (HKSTS), Hong Kong, February 2018.

Plans for Next Reporting Period to Accomplish Technology Transfer Goal: Continue to support researchers as they present their research results through peer-reviewed publications and professional presentations. Organize a Center for Transportation Research (CTR) Symposium to be held April 12, 2018. Work with a new set of summer interns and expose them to the many challenging aspects of data analysis and implications.

2. PRODUCTS

Publications, conference papers, and presentations:

Journal Publications - Published

Jafari, E., and S. D. Boyles. "Online Charging and Routing of Electric Vehicles in Stochastic Time-Varying Networks." *Transportation Research Record: Journal of the Transportation Research Board*, 2667, 61-70, 2017.

Jafari, E., V. Pandey, and S.D. Boyles. "A Decomposition Approach to the Static Traffic Assignment Problem." *Transportation Research Part B,* 105, 270-296, 2017.

Levin, M.W., E. Jafari, R. Shah, and S.D. Boyles. "Network-based Model for Predicting the Effect of Fuel Price on Transit Ridership and Greenhouse Gas Emissions. *International Journal of Transportation Science and Technology*, 6(4), 272-286, 2017.

Sharon, G., M. W. Levin, J. P. Hanna, T. Rambha, S. D. Boyles, and P. Stone. "Network-Wide Adaptive Tolling for Connected and Automated Vehicles." *Transportation Research Part C* 84, 142-157, 2017.

Sharon, G., M. Albert, T. Rambha, S. Boyles, and P. Stone, "Traffic Optimization for a Mixture of Self-interested and Compliant Agents." Proceedings of the 32nd AAAI Conference on Artificial Intelligence (AAAI-18), New Orleans, Louisiana, February 2018.

Astroza, S., A.R. Pinjari, C.R. Bhat, and S.R. Jara-Diaz, "A Microeconomic Theory-Based Latent Class Multiple Discrete-Continuous Choice Model of Time Use and Goods Consumption." *Transportation Research Record: Journal of the Transportation Research Board*, 2664, 31-41, 2017.

Bhat, C.R., S. Astroza, and P.S. Lavieri, "A New Spatial and Flexible Multivariate Random-Coefficients Model for the Analysis of Pedestrian Injury Counts by Severity Level." *Analytic Methods in Accident Research*, 16, 1-22, 2017.

Dias, F.F., P.S. Lavieri, V.M. Garikapati, S. Astroza, R.M. Pendyala, and C.R. Bhat, "A Behavioral Choice Model of the Use of Car-Sharing and Ride-Sourcing Services," *Transportation*, *2017 TRB Annual Meeting Special Issue*, 44(6), 1307-1323, 2017.

Bhat, C.R., and P.S. Lavieri, "A New Mixed MNP Model Accommodating a Variety of Dependent Non-Normal Coefficient Distributions." *Theory and Decision*, 84(2), 239-275, 2018.

Huang, L., W. Xu, S. Liu, V. Pandey and N. R. Juri. "Enabling Versatile Analysis of Large Scale Traffic Video Data with Deep Learning and HiveQL." Proceedings of *2017 IEEE International Conference on Big Data (Big Data)*, Boston, MA, pp. 1153-1162, 2017.

Zhu, D., J. Choi and R.W. Heath, "Two-Dimensional AoD and AoA Acquisition for Wideband Millimeter-Wave Systems With Dual-Polarized MIMO." *IEEE Transactions on Wireless Communications*, 16(12), 7890-7905, December 2017. doi: 10.1109/TWC.2017.2754369

González-Prelcic, N., A. Ali, V. Va, and R.W. Heath Jr., "Millimeter-Wave Communication with Out-of-Band Information." *IEEE Communications Magazine*, 55(12), 140-146, December 2017. doi: 10.1109/MCOM.2017.1700207

Ali, A., N. González-Prelcic, and R.W. Heath Jr., "Millimeter Wave Beam-Selection Using Out-of-Band Spatial Information." *IEEE Transactions on Wireless Communications*, 17(2), 1038-1052, February 2018. doi: 10.1109/TWC.2017.2773532

Daniels, R.C., E.R. Yeh, and R.W. Heath Jr., "Forward Collision Vehicular Radar with IEEE 802.11: Feasibility Demonstration Through Measurements." *IEEE Transactions on Vehicular Technology*, 67(2), 1404-1416, February 2018. doi: 10.1109/TVT.2017.2758581

Chen, Y., X. Yi and C. Caramanis, "Convex and Nonconvex Formulations for Mixed Regression With Two Components: Minimax Optimal Rates." *IEEE Transactions on Information Theory*, 64(3), 1738-1766, March 2018. doi: 10.1109/TIT.2017.2773474

Presentations

Va, V., T. Shimizu, G. Bansal, and R.W. Heath Jr., "Position-aided millimeter wave V2I beam alignment: A learning-to-rank approach." *2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC)*, Montreal, QC, October 2017, pp. 1-5.

Heath, R.W., "Millimeter Wave Communication with Out-of-Band Information." *Invited seminar*, Department of Electrical Engineering, University of Washington, Seattle, WA, October 2, 2017.

Heath, R.W., "Millimeter Wave MIMO Signal Processing." Keynote presentation, *International Conference on Wireless Communications and Signal Processing*, Nanjing, China, October 12, 2017.

Heath, R.W., "Millimeter Wave MIMO Signal Processing." Plenary presentation, *2018 Asilomar Conference on Signals, Systems, and Computers*, Pacific Grove, CA, October 30, 2017.

Ali, A., "Millimeter Wave Spatial Covariance Estimation Using Out-of-Band Information." Poster presented at the *Texas Wireless Summit*, Austin, TX, November 7, 2017.

Kumari, P., "Adaptive IEEE 802.11ad Waveform Design for a Joint Automotive Communication-Radar System." Poster presented at the *Texas Wireless Summit*, Austin, TX, November 7, 2017.

Bhat, C.R., "Connected and Autonomous Vehicles: Where Are We Going and What Happens When We Get There?," *Invited Seminar*, Ferrovial Executive Forum, Madrid, Spain, November 2017.

Heath, R.W., "Millimeter Wave Communication Leveraging Out-of-Band Information." *Invited seminar*, Southern Methodist University, Dallas, TX, November 28, 2017.

Ruiz Juri, N., "Sharing Novel Transportation Data to Promote Innovation through Collaboration: Case Studies from Austin, TX." Presented at the *Visualizing Transportation Big Data for Efficient Decision Making Workshop*, Transportation Institute, University of Florida, Gainesville, FL, December 2018.

Boyles, S., "Parking Search Equilibrium and its Implications for Parking Management." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Buini, H.M., G. Sharon, St. Boyles, T. Givargis and P. Stone, "Enhanced Delta-tolling: Traffic Optimization via Policy Gradient Reinforcement Learning." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Sharon, G., M. Albert, T. Rambha, S. Boyles, and P. Stone, "Traffic Optimization for a Mixture of Self-interested and Compliant Agents." Presented at the *International Symposium on Artificial Intelligence and Mathematics*, Fort Lauderdale, FL, January 2018.

Boyles, S., C. Xie, and X. Wu, "Path-Constrained Traffic Assignment: Continuously Distributed Bounds on Travel Weights." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., and S. Boyles, "Dynamic Pricing for Managed Lanes with Multiple Entrances and Exits." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., C. Yahia, S. Boyles, and J. Li, "Evaluation of Active Traffic Management (ATM) Strategies under Recurring and Non-recurring Congestion: an IH-35 Corridor Case Study." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Yahia, C., V. Pandey, and S. Boyles, "Network Partitioning Algorithms for Solving the Traffic Assignment Problem Using a Decomposition Approach." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V. and N. Ruiz Juri, "Using National Performance Management Research Data Set (NPMRDS) for Corridor Performance Measures: A US-281 N Corridor Case Study." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Pandey, V., W. Xu, L. Huang, S. Liu, and N. Ruiz Juri, "Processing large-scale video data to support transportation safety, planning, and operations: a flexible approach to data storage and integration." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Astroza, S., P.C. Bhat, C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Understanding Activity Engagement Across Weekdays and Weekend Days: A Multivariate Multiple Discrete-Continuous Modeling Approach," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Astroza, S., V.M. Garikapati, R.M. Pendyala, C.R. Bhat, and P.L. Mokhtarian, "Representing Heterogeneity in Structural Relationships Among Multiple Choice Variables Using a Latent Segmentation Approach," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Bhat, C.R., New Matrix-Based Methods for the Analytic Evaluation of the Multivariate Cumulative Normal Distribution Function *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Bhat, C.R., S. Astroza, and P.S. Lavieri, "A Model for the Analysis of Pedestrian Injury Counts by Severity Level," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Dai, Q., P.S. Lavieri, and C.R. Bhat, "Using Virtual Accessibility and Physical Accessibility as Joint Predictors of Activity-Travel Behavior," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

Dias, F.F., S. Astroza, V.M. Garikapati, R.M. Pendyala, C.R. Bhat, and P.L. Mokhtarian, "A Multivariate Exploration of Emotional Feelings of Subjective Well-Being During Travel Episodes," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2018.

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Websites:
http://dstop.utexas.edu, D-STOP website
http://ctr.utexas.edu/, Center for Transportation Research (CTR)
http://ctr.utexas.edu/nmc/, Network Modeling Center at CTR
http://www.datarodeo.org/, Data Rodeo, A Data Analytics Environment for the Central Texas Region
http://wncg.org/, Wireless Networking & Communications Group (WNCG)
http://www.caee.utexas.edu/prof/bhat/fULL_PAPERS.htm, Dr. Bhat's personal webpage
http://tinyurl.com/steveboyles/, Dr. Boyles' personal webpage
http://www.profheath.org/, Dr. Heath's personal webpage

Technologies or techniques: Nothing to report for this period.

Inventions, patent applications, and licenses: Nothing to report for this period.

Other products: Nothing to report for this period.

3. PARTICIPANTS & COLLABORATING ORGANIZATIONS

What organizations have been involved as partners?
City of Austin, Austin, TX: In-kind support, financial support
Texas Department of Transportation, Austin, TX: In-kind support, financial support
North Central Texas Council of Governments (NCTCOG): financial support
Samsung Research America, Dallas, TX: In-kind support
Huawei Technologies, USA: In-kind support, technical consultancy
Cintra, In-kind support, financial support
Universidade de Vigo, Department of Signal Theory and Communications, Vigo, Spain - Nuria G. Prelcic: Technical consultancy.
Sergiy A. Vorobyov, Aalto University, Espoo, Finland, Technical Consultancy
Mohammed E. Eltayeb, California State University, Sacramento, CA, Technical Consultancy
Texas Advanced Computing Center, University of Texas at Austin, technical consultancy
Honda R&D Americas, technical consultancy

Have other collaborators or contacts been involved?
D-STOP has allowed us to build new relationships, including a contract with TxDOT San Antonio District to assist with DTA modeling, and also a new task with TxDOT Austin District to help with planning to use advanced modeling.

We have made DSTOP known to industrial affiliates of the Wireless Networking & Communications Group (WNCG): Crown Castle; Cisco; Huawei; Qualcomm; DOCOMO; Department of Defense; AT&T; CoomScope; National Instruments; Samsung; Yokagawa; Universidade de Vigo, Spain; Toyota; Iteris; Microsoft Research; 3M Traffic Safety Systems; RideScout.

We have also discussed DSTOP with several public agencies who have come on board as members of the D-STOP Business Advisory Council (BAC). These include North Central Texas Council of Governments (NCTCOG), Capital Metro, Austin Chamber of Commerce, the City of Austin, Texas, FHWA Texas Division, and the Texas Dept of Transportation.

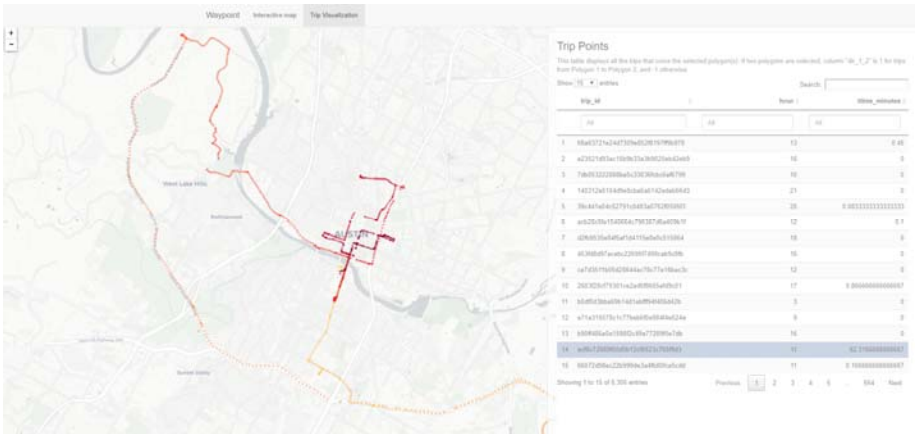
4. IMPACT

Impact on the development of the principal disciplines of the program:
D-STOP projects have informed the development of resilient and redundant communication networks for enhancing traffic safety. At the same time, D-STOP projects have contributed to ways in which traffic mobility and reliability may be improved through a heterogeneous system of wireless sensors.

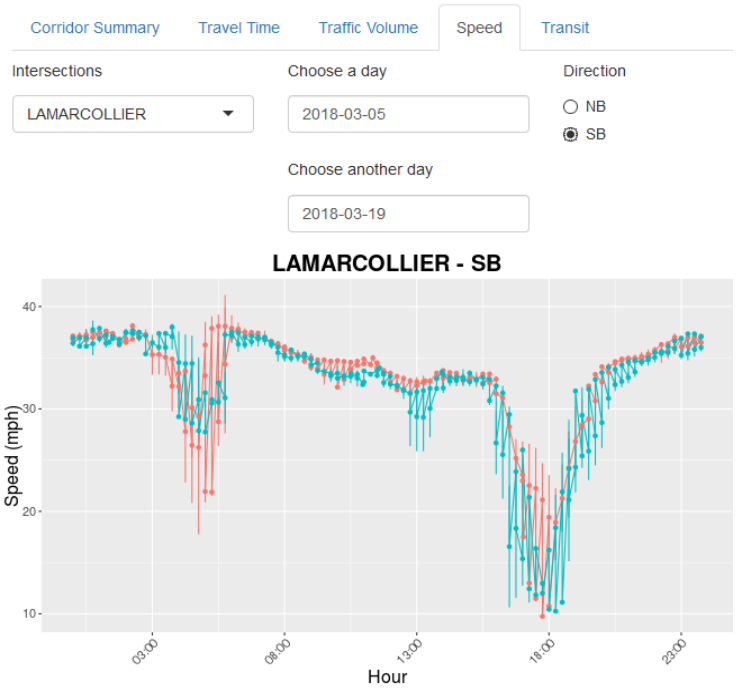
Impact on other disciplines:
The D-STOP research projects involve collaborations with faculty in other disciplines, including electrical engineering and computer science. Several papers contribute in substantive ways to new methods to evaluate the cumulative multivariate normal distribution function, which is used routinely in many fields, including statistics, hydrology, environmental economics, and urban/regional planning.

Impact on the transportation workforce development:
Continuing to prepare the leaders of tomorrow through undergraduate and graduate student research and education. Our students obtain experiential training in real-world problems through our research interactions with practice-oriented agencies such as Capital Area Metropolitan Planning Organization (CAMPO), North Central Texas Council of Governments (NCTCOG), Cintra, and TxDOT. As part of D-STOP activities, we have reached out to high school students in the Austin region, providing a glimpse of the exciting transportation research landscape.

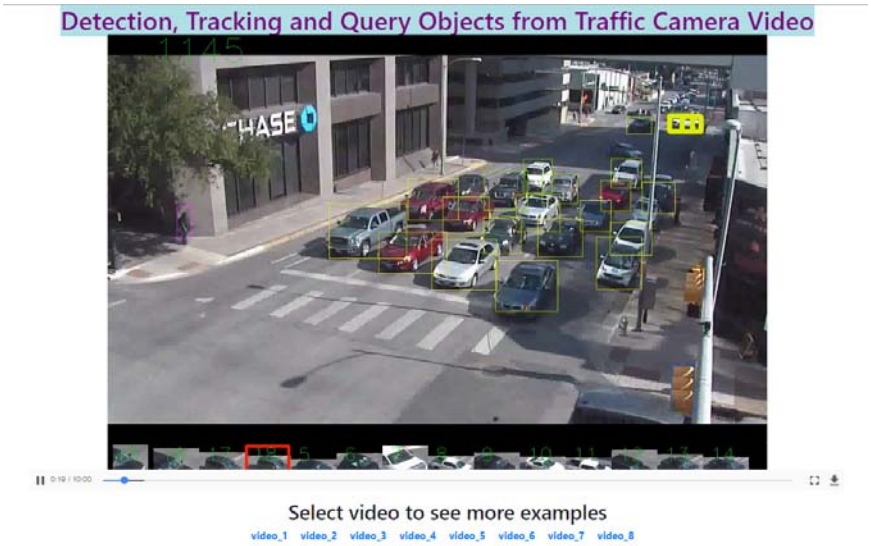
Impact on physical, institutional, and information resources at the university or other partner institutions:
D-STOP research has led to the development of a probe vehicle data analysis tool (http://shiny.utnmc.org/waypoints/):



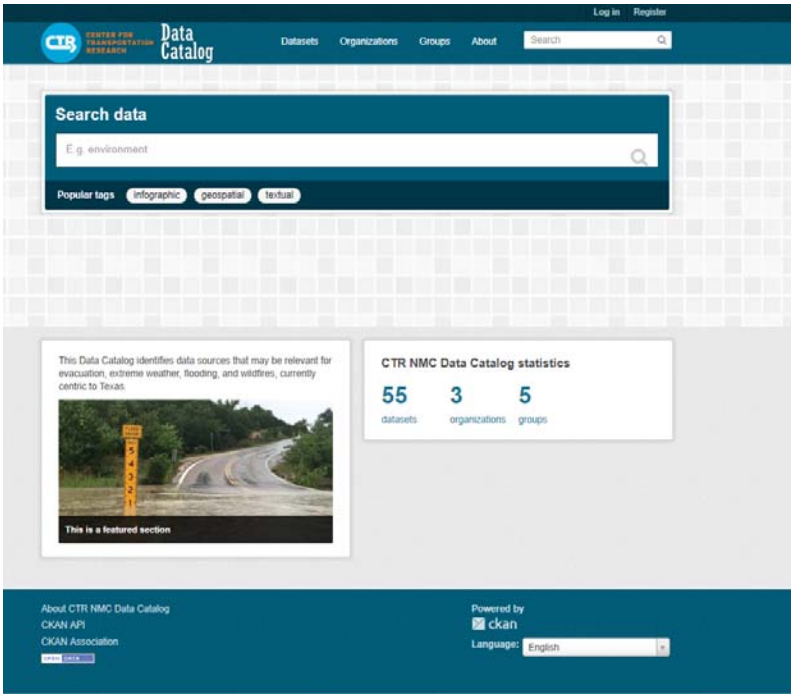
a corridor data aggregation and analysis tool (http://shiny.utnmc.org/hdr_corridor/):



as well as a video data analysis demonstration website (http://soda.tacc.utexas.edu/):



Impact on technology transfer:
The D-STOP team was actually involved in post-Harvey recovery assistance and research, including developing a catalog of weather data sources in Central Texas (http://catalog.utnmc.org/).



Impact on society beyond science and technology:
The models developed under DSTOP-supported research can lead to more efficient and safe use of transportation infrastructure, decreasing congestion, improving roadway safety, and supporting the economic competitiveness of the nation.

5. CHANGES/PROBLEMS

Nothing to report.