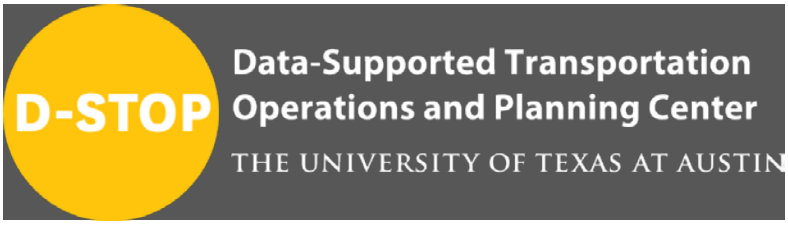
Program Progress Performance Report



Submitted to:	U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology
Federal Grant No.:	DTRT13-G-UTC58
Project Title:	Data-Supported Transportation Operations and Planning (D-STOP) Center
Program Director:	Chandra Bhat, Director, bhat@mail.utexas.edu, 512-471-4535
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Reporting Period End Date:	March 31, 2017
Report Term:	October 1, 2016 – March 31, 2017
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 17 projects were pursued with partial or full funding support from D-STOP. Of these, 4 projects were completed during this reporting period. Currently, 13 projects are underway, with 15 new projects approved by the Business Advisory Council.

Completed Projects

1. **Models for High Dimensional Mixed Regression**
   (Co-PIs: Constantine Caramanis and Chandra Bhat); End date: September 30, 2016

2. **Greedy Subspace Clustering**
   (PI: Constantine Caramanis); End date: September 30, 2016

3. **Travel Modeling in an Era of Connected and Automated Transportation Systems: An Investigation in the Dallas-Fort Worth Area**
   Joint Project with North Central Texas Council of Governments (NCTCOG)
   (PI: Chandra Bhat); End date: December 31, 2016

4. **Online Learning for Freight**
   (PI: Sanjay Shakkottai); End date: December 31, 2016

Ongoing Projects

1. **Semi-Autonomous Parking for Enhanced Safety and Efficiency**
   (PI: Sriram Vishwanath); Anticipated end date: June 30, 2017

2. **Transportation Data Discovery Environment**
   (PI: Jennifer Duthie); Anticipated end date: August 31, 2018

3. **Analyzing Millimeter Wave Vehicular Communication Systems in Urban Areas**
   (PI: Robert Heath); Anticipated end date: May 31, 2017

4. **Exploiting DSRC Information to Reduce Millimeter Wave Beam Alignment Overhead in Vehicular Environments**
   (PI: Robert Heath); Anticipated end date: May 31, 2017

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

6. **Large-Scale Linear Programs in Planning and Prediction**
   (PI: Constantine Caramanis); Anticipated end date: June 30, 2017

7. **Imputing Missing Data via Sparse Reconstruction Techniques**
   (PI: Constantine Caramanis); Anticipated end date: June 30, 2017

8. **Using Collected Data to Improve Dynamic Traffic Assignment Modeling**
   (PI: Jennifer Duthie); Anticipated end date: August 31, 2018

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

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

11. **Blockage Avoidance for Millimeter Wave Vehicular Communications Using Radar**
    (PI: Robert Heath); Anticipated end date: May 31, 2017

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

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

Latest projects approved by the Business Advisory Council:

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

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

16. **Cooperative Mapping for Automated Vehicles**
    (PI: Todd Humphreys); Anticipated end date: September 30, 2017

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

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

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

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

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

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

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

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

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

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

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

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

Research Results Disseminated: 21 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. 38 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>
Lauryn Altena, Jamie Hufnagel, Maitri Zalawadia (supervised by Chandra Bhat)
Maximilian Grether (supervised by Jen Duthie/Stephen Boyles)
Rahul Patel, Tejas Choudhary (supervised by Stephen Boyles)

<u>Grad</u>
Supervised by Chandra Bhat: Sebastian Astroza (PhD), Qichun Dai (MS), Amanda Deering (MS), Felipe Dias (PhD), Patricia Lavieri (PhD), Gopindra Nair (PhD), Priyadarshan Patil (MS), Abhilash Singh (MS), Pragun Vinayak (MS).

Supervised by Stephen Boyles: Dongxu (Henry) He (MS), John Helsel (MS), Ehsan Jafari (PhD), Rachel James (PhD), Michael Levin (PhD), Venktesh Pandey (PhD), Rahul Patel, Cesar Yahia (MS).
Supervised by Jennifer Duthie: Jackson Archer (MS), Hao Pang (PhD), Sara Sadeghi (MS).
Supervised by Constantine Caramanis: Craig Corcoran (PhD), Jessica Hoffman (PhD), Dohyung Park (PhD), Xinyang Yi (PhD).
Supervised by Robert Heath: Anum Ali (PhD), Meixu Chen (MS), Preeti Kumari (MS/PhD), Vutha Va (PhD), Yuyang Wang (MS).
Supervised by Todd Humphreys: Lakshay Narula (MS/PhD).
Supervised by Sanjay Shakkottai: Soumya Basu (PhD).
Supervised by Sriram Vishwanath: Andrew Briggs (PhD), Christopher Snyder (PhD), Muryong Kim (PhD), Hardik Jain (PhD), Subhashini Krishnasamy (PhD).
Supervised by Jeff Andrews: Chang-sik Choi (PhD).
Supervised by Joydeep Ghosh: Ashish Bora (PhD), Rahi Kalantari (PhD), Taewan Kim (PhD), Michael Motro (PhD).

The D-STOP Center selected MS/PhD student Michael Motro (supervised by Dr. Joydeep Ghosh) as its 2016 Outstanding Student of the Year. MS student Venktesh Pandey (supervised by Dr. Stephen Boyles) was awarded the Council of University Transportation Centers (CUTC) 2016 Milton Pikarsky Memorial Award for his MS thesis entitled “Optimal Dynamic Pricing for Managed Lanes with Multiple Entrances and Exits”. Michael and Venktesh were recognized at an annual awards banquet in January 2017 in Washington DC before the TRB Annual Meeting

Education and Workforce Development Results Disseminated:

UT SAVES: The first board meeting of UT SAVES (Situation-Aware Vehicular Engineering Systems), a new Center directed by Dr. Robert Heath, was held October 19, 2016. In partnership with CTR, WNCG has created this Center to address the challenges of wireless, networking, and sensing in vehicular systems. SAVES combines WNCG’s expertise in wireless networking and communications, data, and signal processing, with CTR’s experience in transportation, traffic modeling, policy and planning to help reduce collisions, design faster commutes, and increase connectivity to make the automated aspects of driving more efficient. The three pillars of SAVES include communications (which seek to create higher data rates and lower latency), sensing (to establish better sensing technology and fuse sensor data), and data analytics (so that sensor data can be combined and made available for transportation departments and city planners, giving them a tool to better manage transportation networks and commute times).

Prospective Grad Student Lunch: Dr. Chandra Bhat met with visiting prospective graduate students and current graduate students during a lunch meeting organized by the transportation graduate program on March 3, 2017. 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.

Business Advisory Council Meeting: D-STOP held its second Business Advisory Council meeting on March 10, 2017. The overall purpose of the BAC is to help guide the direction of the D-STOP Center's overall research and education/work force development efforts. Together, the intent is that D-STOP serves not only as a mechanism to undertake cutting edge research of relevance, but also as a vehicle to reduce the incubation time from research to implementation and contribute to the next generation of thought leaders. The BAC meeting helped to (a) provide strategic planning advice to the Center, (b) provide input on Center activities and review/approve project statements for research, (c) identify research projects for further collaborative funding and possible implementation beyond Center funding, and (d) facilitate the collaborative process of linking the Center with private, public, and policy entities, and with regional and national activities.

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:
Continue discussions with the Business Advisory Council (BAC), following on a BAC meeting held March 10, 2017. The University Transportation Center-Undergraduate Internship (UTC-UI) program will be held for a fourth year in the summer of 2017, 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

2016 Texas Wireless Summit
The Texas Wireless Summit (TWS), hosted by the Wireless Networking and Communications Group (WNCG), was held October 18, 2016 at UT Austin. This year's TWS focused on how automated vehicles will re-shape wireless over the next 10 years with their demands for coordinated sensing and decision making. The Summit examined three key aspects of automation: communication, sensing, and data analytics/machine intelligence. D-STOP's Todd Humphreys and Constantine Caramanis 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). This year's keynote speakers included Sanjiv Nanda, VP Engineering with Qualcomm Research, and Peter Stone, Professor of Computer Science and Chair of the Robotics Portfolio Program at UT Austin.

SXSW Panel
Dr. Chandra Bhat was an invited speaker at a panel on "Beyond Driverless Cars: Our Transportation Future" organized by Allstate Insurance at the 2017 SXSW Conference in Austin on March 14, 2017. The purpose of this panel was to explore the economic opportunities the transformation of our transportation system will provide for the U.S. economy and consumers. The panel also highlighted the unprecedented alignment and cooperation required among private and public sectors to make it all happen. Speakers included Anthony Foxx, former U.S. Secretary of Transportation, Don Civgin, President of Emerging Businesses, Allstate Insurance Company, and Neal Ungerleider, Reporter, Fast Company.

Autonomous Electric Mini-Bus Shuttle Demo
Capital Metro, along with transportation partners RATP Dev, McDonald Transit Associates and UT Austin's Center for Transportation Research, provided a demonstration of an EasyMile EZ10 fully autonomous shuttle on March 16-17, 2017 during the SXSW Conference. UT Austin was selected in January 2017 to be a USDOT-approved Autonomous Vehicle Proving Ground. The media and the public were invited to experience what the future of public transportation in Austin (and beyond) will look like. The 12-passenger EZ10 electric Mini-Bus Shuttle ran pre-determined routes within a campus parking lot.

D-STOP Symposium
D-STOP held its third annual symposium, "Automated Vehicles Workshop", on February 13, 2017 (see attached agenda). It focused specifically on automated vehicles, and was held in conjunction with the North Central Texas Council of Governments (NCTCOG) at their offices in Arlington, Texas. The half-day event presented topics such as a technology overview of connected and autonomous vehicles and their role in urban planning and modeling; how autonomous vehicles could impact travel patterns; how governments and researchers can prepare for a more connected future; how cars and infrastructure can communicate with each other and the resulting security and privacy issues this raises; data analytics and where data can be processed within this new system; and finally, what role data will play in helping with

efficient planning and operation. NCTCOG's Program Manager for Automated Vehicles, Tom Bamonte, and D-STOP Director Dr. Chandra Bhat, moderated the event. Featured speakers included CTR and WNCG research experts Drs. Chandra Bhat, Natalia Ruiz, Jennifer Duthie, Sanjay Shakkottai, Constantine Caramanis, and researcher James Kuhr. Roughly 150 people attended the day's event, including NCTCOG members and staff as well as private sector representatives from the Dallas-Fort Worth area.

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

Published:

Moharir, S. S. Krishnasamy and S. Shakkottai, "Scheduling in Densified Networks: Algorithms and Performance". IEEE/ACM Transaction on Networking, 25(1), pp 164-178, 2017.

Bhatti, J. and T. Humphreys. "Hostile control of ships via false GPS signals: Demonstration and detection," *Navigation, Journal of the Institute of Navigation*, 64(1), 51-66, 2017.

Levin, M.W., H. Fritz, and S.D. Boyles. On Optimizing Reservation-Based Intersection Controls. *IEEE Transactions on Intelligent Transportation Systems*, 18(3), 505-515, March 2017.

Bhat, C.R., S. Astroza, and A.S. Hamdi, "A Spatial Generalized Ordered-Response Model with Skew Normal Kernel Error Terms with an Application to Bicycling Frequency," *Transportation Research Part B*, 95, 126-148, 2017.

Motro, M., A. Chu, J. Choi, P.S. Lavieri, A.R. Pinjari, C.R. Bhat, J. Ghosh and R.W. Heath Jr., "Vehicular Ad-Hoc Network Simulations of Overtaking Maneuvers on Two-Lane Rural Highways," *Transportation Research Part C*, 72, 60-76, 2016.

Kumar, V., C.R. Bhat, R.M. Pendyala, D. You, E. Ben-Elia, and D. Ettema, "Impacts of Incentive-Based Intervention on Peak Period Traffic: Experience from the Netherlands," *Transportation Research Record: Journal of the Transportation Research Board*, 2543, 166-175, 2016.

Lavieri, P.S., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Introducing Latent Psychological Constructs in Injury Severity Modeling: Multivehicle and Multioccupant Approach," *Transportation Research Record: Journal of the Transportation Research Board*, 2601, 110-118, 2016.

Bhat, C.R., A.R. Pinjari, S.K. Dubey, and A.S. Hamdi, "On Accommodating Spatial Interactions in a Generalized Heterogeneous Data Model (GHDM) of Mixed Types of Dependent Variables," *Transportation Research Part B*, 94, 240-263, 2016.

Choi, J., V. Va, N. Gonzalez-Prelcic, R. Daniels, C.R. Bhat, and R.W. Heath Jr., "Millimeter-Wave Vehicular Communication to Support Massive Automotive Sensing," *IEEE Communications Magazine*, 54(12), 160-167, December 2016.

Rambha, T., and S.D. Boyles, "Dynamic Pricing in Discrete Time Stochastic Day-to-Day Route Choice Models." *Transportation Research Part B*, 92A, 104-118, 2016.

Patel, R., Levin, M.W., and S.D. Boyles. Effects of autonomous vehicle behavior on arterial and freeway networks. *Transportation Research Record*, 2561, 9-17, 2016.

Duell, M., M.W. Levin, S.D. Boyles, and S.T. Waller. Impact of autonomous vehicles on traffic management: case of dynamic lane reversal. *Transportation Research Record*, 2561, 87-94, 2016.

Gupta, A., W. Xu, N. Ruiz-Juri and K. Perrine, "A workload aware model of computational resource selection for big data applications," Proceedings of *2016 IEEE International Conference on Big Data (Big Data)*, Washington DC, pp. 2243-2250, 2016

Xu, W., N.R. Juri, A. Gupta, A. Deering, C. Bhat, J. Kuhr, and J. Archer, "Supporting large scale connected vehicle data analysis using HIVE," Proceedings of *2016 IEEE International Conference on Big Data (Big Data)*, Washington DC, pp. 2296-2304, 2016.

Wang, Y., K. Venugopal, A. F. Molisch and R. W. Heath Jr. "Analysis of Urban Millimeter Wave Microcellular Networks." *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

Eltayeb, M.E., J. Choi, T.Y. Al-Naffouri and R.W. Heath Jr., "On the Security of Millimeter Wave Vehicular Communication Systems Using Random Antenna Subsets," *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

Va, V. and R. W. Heath Jr. (2016). "Performance Analysis of Beam Sweeping in Millimeter Wave Assuming Noise and Imperfect Antenna Patterns," *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

Va, V., H. Vikalo, and R. W. Heath Jr., "Beam tracking for mobile millimeter wave communications systems," *Proceedings of the IEEE* Global Conference on Signal and Information Processing (*GlobalSIP)*, Washington DC, December, pp. 743-747, 2016.

Ali, A., N. González Prelcic, and R.W. Heath, Jr., "Estimating Millimeter Wave Channels using Out-of-Band Measurements," *Proceedings of the 2016 Information Theory and Applications Workshop (ITA)*, La Jolla, CA, 2016.

González Prelcic, N., R. Méndez-Rial, and R.W. Heath, Jr., "Radar Aided Beam Alignment in MmWave V2I Communications Supporting Antenna Diversity, " *Proceedings of the 2016 Information Theory and Applications Workshop (ITA)*, La Jolla, CA, 2016.

Krishnasamy, S., R. Sen, R. Johari and S. Shakkottai, "Regret of Queueing Bandits". Advances in Neural Information Processing Systems 29, *Proceedings of the 30th Annual Conference on Neural Information Processing Systems (NIPS)*, Barcelona, Spain, December 2016.

Forthcoming:

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*, forthcoming

Astroza, S., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, P.S. Lavieri, and F. Dias, "Analysis of the Impact of Technology Use on Multi-Modality and Activity-Travel Characteristics," *Transportation Research Record: Journal of the Transportation Research Board*, forthcoming

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*, *TRB 2017 Special Issue*, forthcoming

Lavieri, P., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, S. Astroza, and F. Dias, "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle Technologies," *Transportation Research Record: Journal of the Transportation Research Board*, forthcoming

Yeh, E.R., J. Choi, N.G. Prelcic, C.R. Bhat, and R.W. Heath Jr., "Security in Automotive Radar and Vehicular Networks," *Microwave Journal*, forthcoming.

Levin, M. W., T. Li, S. D. Boyles, and K. M. Kockelman. A general framework for modeling shared autonomous vehicles, with dynamic ride-sharing and dynamic traffic assignment application. *Computers, Environment and Urban Systems*, forthcoming.

Shah, R., P. Bansal, and S. D. Boyles. Robust network pricing and system optimization under combined long-term stochasticity and elasticity of travel demand. *Transportation*, forthcoming.

Jafari, E., and S. D. Boyles. On-line charging and routing of electric vehicles in stochastic time-varying networks. *Transportation Research Record*, forthcoming.

Wang, Y., K. Venugopal, A.F. Molisch and R.W. Heath Jr., "Blockage and coverage analysis with mmWave cross street BSs near urban intersections," to appear in *IEEE International Conference on Communications* (ICC'17), May, 2017, Paris, France.

Ali, A. and R.W. Heath Jr., "Compressed Beam-selection in Millimeter Wave Systems with Out-of-Band Partial Support Information," to appear in *Proceedings of International Conference on Acoustics, Speech and Signal Processing (ICASSP)*, New Orleans, March 2017.

Eltayeb, M.E., J. Choi, T.Y. Al-Naffouri, and R. W. Heath Jr., "Enhancing Secrecy with Multi-Antenna Transmission in Millimeter Wave Vehicular Communication Systems," to appear in *IEEE Transactions on Vehicular Technology*.

Va, V., J. Choi, and R. W. Heath Jr., "The Impact of Beamwidth on Temporal Channel Variation in Vehicular Channels and its Implications," to appear in *IEEE Transactions on Vehicular Technology*.

Sen, R., K. Shanmugam, A. Dimakis and S. Shakkottai, "Contextual Bandits with Latent Confounders: An NMF Approach," to appear in the *Proceedings of the 20th International Conference on Artificial Intelligence and Statistics (AISTATS 2017)*, Ft. Lauderdale, FL, April 2017

Krishnasamy, S., P. T. Akhil, A. Arapostathis, S. Shakkottai and R. Sundaresan, "Augmenting Max-Weight with Explicit Learning for Wireless Scheduling with Switching Costs," to appear in *Proceedings of IEEE International Conference on Computer Communications*, Atlanta, GA, May 2017.

Pesyna, Jr., T. E. Humphreys; R. W. Heath; T. D. Novlan; J. C. Zhang, "Exploiting Antenna Motion for Faster Initialization of Centimeter-Accurate GNSS Positioning with Low-Cost Antennas," to appear in *IEEE Transactions on Aerospace and Electronic Systems*.

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

Rambha, T., S.D. Boyles, and A. Unnikrishnan, "A Destination-based Algorithm for User Equilibrium with Recourse Using Split Proportions," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Pandey, V. and S.D. Boyles, "Optimal Pricing for Managed Lanes With Multiple Entrances And Exits," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Boyles, S.D. and E. Jafari, "Multicriteria Shortest Path Problem for Electric Vehicles in Stochastic Networks," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Ali, A., N. González-Prelcic, and R.W. Heath Jr., "Beam-training in mmWave using out-of-band information," Poster presented at the *Texas Wireless Summit*, Austin, TX, October 2016.

Va, V. J. Choi, T. Shimizu, G. Bansal, and R.W. Heath Jr., "Multipath fingerprint based beam alignment for millimeter wave V2I communications," Poster presented at the *Texas Wireless Summit*, Austin, TX, October 2016.

Kuhr, J., "Coming Soon to a Highway Near You," *The Bond Buyer's Transportation Finance/P3 Conference*, Dallas, TX, November 2016.

Bhat, C.R., "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle (AV) Technologies," *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, November 2016.

Bhat, C.R., P.S. Lavieri, and S. Astroza, "On Identifying Engineering and Behavioral Countermeasures to Reduce the Occurrence and Severity of Pedestrian Injuries in Vehicle-Pedestrian Crashes," *10th University Transportation Centers Spotlight Conference on Pedestrian and Bicycle Safety*, Washington, DC, December 2016.

Bhat, C.R., "Transportation Analytics in a New Data Landscape," Keynote presentation, *International Conference on Transportation Planning and Implementation Methodologies for Developing Countries (TPMDC2016)*, Mumbai, India, December 2016.

Va, V., H. Vikalo, and R.W. Heath Jr., "Beam tracking for mobile millimeter wave communications systems," IEEE Global Conference on Signal and Information Processing (GlobalSIP), Washington D.C., December 2016.

Ali, A. and R.W. Heath Jr., "Beam-Selection in Millimeter Wave Using Out-of-Band Information," Poster presented at the *WNCG Open House*, Austin, TX, January 2017.

Va, V. J. Choi, T. Shimizu, G. Bansal, and R.W. Heath Jr., "Multipath fingerprint based beam alignment for millimeter wave V2I communications," Poster presented at the *WNCG Open House*, Austin, TX, January 2017.

Astroza, S., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, P.S. Lavieri, and F. Dias, "Analysis of the Impact of Technology Use on Multi-Modality and Activity-Travel Characteristics," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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 Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., "Collaboration and the New Data Landscape for Modeling and Planning," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., S. Astroza, and A. Hamdi, "On Recognizing Social Interaction Effects in Bicycling Use and Frequency," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., and P.S. Lavieri, "A New Mixed MNP Model Accommodating a Variety of Dependent Non-Normal Coefficient Distributions," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., A.R. Pinjari, S.K. Dubey, and A. Hamdi, "Joint Mixed Spatial Model of Household Residential Choice, Vehicle Ownership, Commute Travel Mode Choice, and Children's School Travel Mode Choice," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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Kuhr, J., C.R. Bhat, J. Duthie, and N. Ruiz, "Ridesharing & Public-Private Partnerships: Current Issues, A Proposed Framework and Benefits," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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Ali, A. and R.W. Heath Jr., "Compressed Beam-Selection in Millimeter Wave Systems with Out-of-band Partial Support Information," International Conference on Acoustics, Speech and Signal Processing (ICASSP), New Orleans, March 2017.

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 13, 2017.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

Moharir, S. S. Krishnasamy and S. Shakkottai, “Scheduling in Densified Networks: Algorithms and Performance”. IEEE/ACM Transaction on Networking, 25(1), pp 164-178, 2017.

Bhatti, J. and T. Humphreys. "Hostile control of ships via false GPS signals: Demonstration and detection," *Navigation, Journal of the Institute of Navigation*, 64(1), 51-66, 2017.

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Kumar, V., C.R. Bhat, R.M. Pendyala, D. You, E. Ben-Elia, and D. Ettema, "Impacts of Incentive-Based Intervention on Peak Period Traffic: Experience from the Netherlands," *Transportation Research Record: Journal of the Transportation Research Board*, 2543, 166-175, 2016.

Lavieri, P.S., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Introducing Latent Psychological Constructs in Injury Severity Modeling: Multivehicle and Multioccupant Approach," *Transportation Research Record: Journal of the Transportation Research Board*, 2601, 110-118, 2016.

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Rambha, T., and S.D. Boyles, "Dynamic Pricing in Discrete Time Stochastic Day-to-Day Route Choice Models." *Transportation Research Part B*, 92A, 104-118, 2016.

Patel, R., Levin, M.W., and S.D. Boyles. Effects of autonomous vehicle behavior on arterial and freeway networks. *Transportation Research Record*, 2561, 9-17, 2016.

Duell, M., M.W. Levin, S.D. Boyles, and S.T. Waller. Impact of autonomous vehicles on traffic management: case of dynamic lane reversal. *Transportation Research Record*, 2561, 87-94, 2016.

Gupta, A., W. Xu, N. Ruiz-Juri and K. Perrine, "A workload aware model of computational resource selection for big data applications," Proceedings of *2016 IEEE International Conference on Big Data (Big Data)*, Washington DC, pp. 2243-2250, 2016

Xu, W., N.R. Juri, A. Gupta, A. Deering, C. Bhat, J. Kuhr, and J. Archer, "Supporting large scale connected vehicle data analysis using HIVE," Proceedings of *2016 IEEE International Conference on Big Data (Big Data)*, Washington DC, pp. 2296-2304, 2016.

Wang, Y., K. Venugopal, A. F. Molisch and R. W. Heath Jr. "Analysis of Urban Millimeter Wave Microcellular Networks." *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

Eltayeb, M.E., J. Choi, T.Y. Al-Naffouri and R.W. Heath Jr., "On the Security of Millimeter Wave Vehicular Communication Systems Using Random Antenna Subsets," *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

Va, V. and R. W. Heath Jr. (2016). "Performance Analysis of Beam Sweeping in Millimeter Wave Assuming Noise and Imperfect Antenna Patterns," *Proceedings of the IEEE 84th Vehicular Technology Conference (VTC-Fall)*, Montreal, Canada, Sept 18-21, 2016.

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Ali, A., N. González Prelcic, and R.W. Heath, Jr., "Estimating Millimeter Wave Channels using Out-of-Band Measurements," *Proceedings of the 2016 Information Theory and Applications Workshop (ITA)*, La Jolla, CA, 2016.

González Prelcic, N., R. Méndez-Rial, and R.W. Heath, Jr., "Radar Aided Beam Alignment in MmWave V2I Communications Supporting Antenna Diversity, " *Proceedings of the 2016 Information Theory and Applications Workshop (ITA)*, La Jolla, CA, 2016.

Krishnasamy, S., R. Sen, R. Johari and S. Shakkottai, "Regret of Queueing Bandits". Advances in Neural Information Processing Systems 29, *Proceedings of the 30th Annual Conference on Neural Information Processing Systems (NIPS)*, Barcelona, Spain, December 2016.

Presentations

Rambha, T., S.D. Boyles, and A. Unnikrishnan, "A Destination-based Algorithm for User Equilibrium with Recourse Using Split Proportions," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Pandey, V. and S.D. Boyles, "Optimal Pricing for Managed Lanes With Multiple Entrances And Exits," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Boyles, S.D. and E. Jafari, "Multicriteria Shortest Path Problem for Electric Vehicles in Stochastic Networks," *INFORMS Annual Meeting*, Nashville, TN, October 2016.

Ali, A., N. González-Prelcic, and R.W. Heath Jr., "Beam-training in mmWave using out-of-band information," Poster presented at the *Texas Wireless Summit*, Austin, TX, October 2016.

Va, V. J. Choi, T. Shimizu, G. Bansal, and R.W. Heath Jr., "Multipath fingerprint based beam alignment for millimeter wave V2I communications," Poster presented at the *Texas Wireless Summit*, Austin, TX, October 2016.

Kuhr, J., "Coming Soon to a Highway Near You," *The Bond Buyer's Transportation Finance/P3 Conference*, Dallas, TX, November 2016.

Bhat, C.R., "Modeling Individual Preferences for Ownership and Sharing of Autonomous Vehicle (AV) Technologies," *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, November 2016.

Bhat, C.R., P.S. Lavieri, and S. Astroza, "On Identifying Engineering and Behavioral Countermeasures to Reduce the Occurrence and Severity of Pedestrian Injuries in Vehicle-Pedestrian Crashes," *10th University Transportation Centers Spotlight Conference on Pedestrian and Bicycle Safety*, Washington, DC, December 2016.

Bhat, C.R., "Transportation Analytics in a New Data Landscape," Keynote presentation, *International Conference on Transportation Planning and Implementation Methodologies for Developing Countries (TPMDC2016)*, Mumbai, India, December 2016.

Va, V., H. Vikalo, and R.W. Heath Jr., "Beam tracking for mobile millimeter wave communications systems," IEEE Global Conference on Signal and Information Processing (GlobalSIP), Washington D.C., December 2016.

Ali, A. and R.W. Heath Jr., "Beam-Selection in Millimeter Wave Using Out-of-Band Information," Poster presented at the *WNCG Open House*, Austin, TX, January 2017.

Va, V. J. Choi, T. Shimizu, G. Bansal, and R.W. Heath Jr., "Multipath fingerprint based beam alignment for millimeter wave V2I communications," Poster presented at the *WNCG Open House*, Austin, TX, January 2017.

Astroza, S., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, P.S. Lavieri, and F. Dias, "Analysis of the Impact of Technology Use on Multi-Modality and Activity-Travel Characteristics," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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 Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., "Collaboration and the New Data Landscape for Modeling and Planning," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Bhat, C.R., S. Astroza, and A. Hamdi, "On Recognizing Social Interaction Effects in Bicycling Use and Frequency," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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Motro, M., A. Chu, J. Choi, P.S. Lavieri, A.R. Pinjari, C.R. Bhat, J. Ghosh and R.W. Heath Jr., "Vehicular Ad-Hoc Network (VANET) Simulations of Overtaking Maneuvers on Two-Lane Rural Highways," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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Duthie, J. and J. Kressner, "Innovation Gaps and Opportunities from TRB ITM 2016," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

Kuhr, J., C.R. Bhat, J. Duthie, and N. Ruiz, "Ridesharing & Public-Private Partnerships: Current Issues, A Proposed Framework and Benefits," *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2017.

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Shakkottai, S., "The Value of Communication and Infrastructure for Automated Cars," *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Arlington, TX, February 2017.

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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
Capital Area Metropolitan Planning Organization (CAMPO): In-kind support
Samsung Research America, Dallas, TX: In-kind support
Huawei Technologies, USA: In-kind support, financial support
Cintra, In-kind support, financial support
TOYOTA InfoTechnology Center, U.S.A., Inc. - Takayuki Shimizu and Gaurav Bansal: Financial support and technical consultancy
Pohang University of Science and Technology, Korea - Junil Choi: Technical consultancy
Universidade de Vigo, Department of Signal Theory and Communications, Vigo, Spain - Nuria G. Prelcic: Technical consultancy.
Haris Vikalo, University of Texas at Austin: Technical consultancy
Kiran Venugopal, University of Texas at Austin: Technical consultancy
Mattan Erez, University of Texas at Austin: Technical consultancy
University of Southern California, Dept of Electrical Engineering, Andreas Molisch: Technical consultancy
Texas Advanced Computing Center, University of Texas at Austin, technical consultancy

Have other collaborators or contacts been involved?
D-STOP has allowed us to build new relationships, including a new 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 communication protocols for V2V and V2I communications, including ways to protect against cybersecurity attacks. At the same time, D-STOP projects have contributed to ways in which safety from crashes can be improved on our roadways.

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 econometric techniques, high dimensional statistical analysis, optimization methods, and data fusion approaches.

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.

Impact on physical, institutional, and information resources at the university or other partner institutions:
Implementing radar systems using low-frequency WiFi signals with NI equipment, and will implement mmWave joint radar and communication systems with NI equipment.

Impact on technology transfer:
The Business Advisory Council meeting provided a forum for the exchange of ideas and thoughts, and the identification of gaps in our current D-STOP activities. The D-STOP team visited with the North Central Texas Council of Governments to discuss the potential impact of connected and automated vehicles on our society.

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.

Data Supported Transportation Operations and Planning (D-STOP) Symposium
"Automated Vehicles Workshop"

Monday, February 13, 2017
North Central Texas Council of Governments (NCTCOG), Transportation Council Room
616 Six Flags Drive, Arlington, Texas

Agenda

- **Introduction – Tom Bamonte, NCTCOG's Program Manager for Automated Vehicles; Dr. Chandra Bhat, D-STOP Director**

Session A: Dr. Chandra Bhat, Dr. Natalia Ruiz and James Kuhr

- **Connected and Autonomous Vehicles: The Enabling Technologies & Their Incorporation in Planning and Modeling** (James Kuhr): Just what is that thing on top of the Google Car? What does adaptive cruise control with lane assist mean? When are these things going to be ready? The answer to these questions and more in a technology overview that unravels just how these vehicles are going to work.
- **Activity Travel Impacts: What Happens When Food Can Deliver Itself?** (Chandra Bhat): Ridesharing services are already changing the transportation paradigm. If autonomous vehicles are introduced what other impacts could they have? Is traffic going to get better…or worse? We will cover potential impacts that begin on the roadway and lead to areas that could impact society tremendously.
- **Planning for a Connected and Autonomous Future** (Natalia Ruiz): How do we prepare for the next 40 years? Do we need to worry about this now? What do we know about the timeline? We will explore what we know now and what we need to consider going forward.

Q&A – Conversation with the research team and audience about technologies and preparing for the future.

BREAK: Technology Demo

Session B: Dr. Jennifer Duthie, Dr. Sanjay Shakkottai, and Dr. Constantine Caramanis

- **The Value of Communication and Infrastructure for Automated Cars** (Sanjay Shakkottai): How do cars talk to each other? Is DSRC enough? Do we need to make our traffic lights talk back? This talk will feature an overview of Vehicle-to-Vehicle and Vehicle-to-Infrastructure communication, explain why it might be necessary and explore current market concerns involving security and privacy.
- **Data Analytics: Challenges and the Internet of Moving Things** (Constantine Caramanis): How do we address the key challenges of IoMT? Where does computing take place? Where do we place the sensors? This presentation explores those issues.
- **Data Confederation and Use** (Jennifer Duthie): What role will data play in connected and autonomous vehicles? What data sources are available to us? What are other entities doing with data? We will explore what other jurisdictions are doing and take time to focus on efforts in Texas to gather an analyze data for operational and planning efficiencies.

Q&A – Conversation with the research team and audience about technologies and opportunities for the DFW region.