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

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Submission Date: October 30, 2016

DUNS Number: 170230239

EIN Number: 746000203

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Recipient Identifying No: OSP 201300867-001

Grant Period: September 30, 2013 – September 30, 2018

Reporting Period End Date: September 30, 2016

Report Term: April 1, 2016 – September 30, 2016

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 23 projects were pursued with partial or full funding support from D-STOP. Of these, 7 projects were completed during this reporting period. Currently, 16 projects are underway.

Completed Projects

1. **Semi-Autonomous Parking for Enhanced Safety and Efficiency**
   (PI: Sriram Vishwanath); End date: April 1, 2016

2. **Combining Millimeter-Wave Radar and Communication Paradigms for Automotive Applications: A Signal Processing Approach**
   (Co-PI: Robert Heath and Chandra Bhat); End date: May 31, 2016

3. **Improved Traffic Operations through Real-Time Data Collection and Control**
   (Co-PIs: Stephen Boyles and Sanjay Shakkottai); End date: May 31, 2016

4. **Streaming PCA with Many Missing Entries**
   (PI: Constantine Caramanis); End date: December 31, 2015 (missing from last reporting period)

5. **High-precision GPS Vehicle Tracking to Improve Safety**
   (Co-PIs: Jennifer Duthie and Todd Humphreys); End date: August 31, 2016

6. **The Formulation and Estimation of a Spatial Skew-Normal Generalized Ordered-Response Model**
    (PI: Chandra Bhat); End date: June 30, 2016

7. **A Latent Class Multiple Constraint Multiple Discrete-Continuous Extreme Value Model of Time Use and Goods Consumption**
    (PI: Chandra Bhat); End date: June 30, 2016

Ongoing Projects

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

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

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

4. **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); Anticipated end date: December 31, 2016

5. **Analyzing Millimeter Wave Vehicular Communication Systems in Urban Areas**
    (PI: Robert Heath); Anticipated end date: May 31, 2017
    The project aims at developing a tractable model by stochastic geometry to analyze the performance of these vehicular networks in urban environments and the effects of the on line-of-sight (LOS) distance, non-line-of-sight (NLOS) interferers. Given the intensity of the streets and transmitters as well as the statistics of vehicular mobility, it is possible to evaluate the vehicular network in terms of coverage probability and capacity. These results will reveal insights about how to give the optimal strategy of deploying the base stations under different vehicular environment.

6. **Exploiting DSRC Information to Reduce Millimeter Wave Beam Alignment Overhead in Vehicular Environments**
    (PI: Robert Heath); Anticipated end date: May 31, 2017
    This project aims at developing an efficient beam alignment algorithm for millimeter wave (mmWave) vehicular communications taking advantage of the side information available in vehicular context. Due to its propagation characteristics, the antenna gains from directional beams are necessary to maintain link quality, but these gains can be achieved only when beams are properly aligned. Conventional methods, such as the one proposed in the IEEE 802.11ad standard, do not use any side information and must endure large overhead that is unacceptable in mobile environments. In this project, we will focus on the DSRC, which exchanges basic safety messages that convey potential useful information for beam alignment such as position, speed, and acceleration of each vehicle. The outcome of this project is an algorithm with two components. The first one will use position information to efficiently perform initial beam alignment, while the second one will make use of kinematic information (e.g., velocity) to maintain the alignment. This algorithm will be essential in providing robust mmWave links that support high data rates to enable automated driving.

7. **Real-Time Signal Control and Traffic Stability**
    (PI: Stephen Boyles); Anticipated end date: August 31, 2018
    Congestion on urban arterials is largely centered around intersection control. Traditional traffic signal schemes are limited in their ability to adapt in real time to traffic conditions or by their ability to coordinate with each other to ensure adequate performance. Specifically, there is a tension between adaptivity (as with actuated signals) and coordination through pre-timed signals (signal progression). We propose to investigate whether routing protocols in telecommunications networks can be applied to resolve these problems. Specifically, the backpressure algorithm of Tassiulas & Emphremides

(1992) can ensure system stability through decentralized control under relatively weak regularity conditions. It is as yet unknown whether this algorithm can be adapted to traffic signal systems, and if so, what modifications are needed. Determining whether (and how) the backpressure concept can be adapted to traffic networks requires significant research, and has the potential to dramatically improve signal performance.

8. **Online Learning for Freight**
   (PI: Sanjay Shakkottai); Anticipated end date: December 31, 2016
   As recently noted by The Economist, a large part of the freight trucking market is unconsolidated. There is a major opportunity to develop online platforms that match individual consumers (people who need freight delivery) with the resource suppliers (individual trucks and truckers). Such platforms can be game-changers, and dramatically improve the efficiency of freight haulage. At the core of this platform is a matching algorithm. This needs to learn from online data—learn both current supply (available trucks and their preferences) and demand (packages to be transported)—and match supply and demand in an online manner. Our research will focus on developing matching algorithms for this setting.

9. **Large-Scale Linear Programs in Planning and Prediction**
   (PI: Constantine Caramanis); Anticipated end date: June 30, 2017
   Large-scale linear programs are at the core of many traffic-related optimization problems in both planning and prediction. Moreover, many of these involve significant uncertainty, and hence are modeled using either chance constraints, or robust optimization. Chance constraints and robust optimization are by now classical approaches for dealing with uncertainty. The ultimate goal in each of these areas, is to find an explicit convex reformulation that provides some approximation to the original (uncertain) optimization problem. The work in these areas has helped us obtain a nearly comprehensive understanding of when convex reformulations (and approximations) are possible, and what the quality of the approximation is. Yet little has been said about truly tractable solutions— solutions where running time for the uncertain problem is comparable (perhaps even less than!) the time to solve the problem without any uncertainty. As networks grow in size, and our ability to capture more data rapidly increases, it is of paramount importance to rethink our theory of robust and uncertain optimization for transportation applications, to one that is computationally oriented.

10. **Imputing Missing Data via Sparse Reconstruction Techniques**
    (PI: Constantine Caramanis); Anticipated end date: June 30, 2017
    The State of Texas does not currently have an automated approach for estimating volumes for links without counts. This research project proposes the development of an automated system to efficiently estimate the traffic volumes on uncounted links, in the event of rare disturbances of the typical traffic flow. The idea we plan to leverage is that the road network provides a mixing effect, whereby localized disturbances (accidents, flooding, road damage, etc.) have an impact whose effect can be measured at many places across the city. This forms the important analog to the well-known uncertainty principle, whereby a signal cannot be sparse in both the time and frequency domains—a result that is critically utilized in the signal reconstruction algorithms for fMRI.

11. **Using Collected Data to Improve Dynamic Traffic Assignment Modeling**
    (PI: Jennifer Duthie); Anticipated end date: August 31, 2018
    Traffic assignment models depend on collected data for calibration and validation. The City of Austin is currently deploying an array of sensors and other equipment to collect new sources of data for the City's transportation system. In addition, other area agencies are collecting large quantities of data and are contributing to the trend of deploying new equipment in the field. Collecting and ultimately using this data to inform transportation network models will result in improved accuracy and can enhance the capabilities of the Center for Transportation's dynamic traffic assignment tools. In addition, the data collection and analysis will spur new research opportunities.

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

In this project, we will formulate a copula-based framework to accommodate non-normal continuous mixing distributions in the MNP model. This approach will allow a multivariate mixing distribution that can combine any continuous distributional shape for each coefficient, including (but not limited to) the skew-normal distribution. The procedure will be based on generating a multivariate continuous distribution through the use of specified parametric univariate continuous coefficient distributions (that can be different for different coefficients) combined with a Gaussian Copula. This research will also propose two alternative estimation procedures for the new model. The effectiveness of the formulation and inference approach will be demonstrated through simulations and an empirical application.

13. **Internet of Moving Things using Full Duplex Mesh Networks**
(PI: Sriram Vishwanath); Anticipated end date: December 31, 2018
Through years of research, we have developed true full duplex communication systems (transmission and reception in the same band at the same time) using novel off the shelf components. Such radios are unique in their ability to listen while transmitting at the same frequency at the same time. Although other full duplex technologies exist (from work conducted at Stanford, Rice and Columbia), these technologies are typically antenna or custom-chip based. Our solution is unique in that it is based on off-the-shelf discrete components together with software. This ability to build a software-centric full duplex solution has many advantages, including low-cost, rapid reconfigurability, and agility. Full duplex radios are able to listen and talk simultaneously, making them ideally suited for mesh networking applications. Conventional mesh networking is highly prone to poor performance due to massive overheads and rigidity. Full duplex radios are much more flexible and adaptable, and can perform tasks such as handoff and scheduling in a low-overhead, rapid manner. This makes them ideally suited to be the basis for the Internet of Moving Things (IoMT). IoMT aims to connect all moving (and static) objects with one another—buses, cars, people, even their pets—without using a cellular or satellite backbone. It enables vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) connectivity in a much more seamless fashion than currently thought possible. Full duplex based IoMT will provide low-cost connectivity between people, while helping us understand how people and vehicles move.

14. **Blockage Avoidance for Millimeter Wave Vehicular Communications Using Radar**
(PI: Robert Heath); Anticipated end date: May 31, 2017
Due to the highly directional nature of millimeter wave (mmWave), mmWave communications are vulnerable to blockage. Next-generation vehicles will be equipped with several sensors, including radars that will provide valuable information about the environment. This project proposes to use radar data as side-information to avoid blockage in vehicular mmWave links. In particular, algorithms will be developed to process the raw data collected by radar to infer the blockage between the mmWave transmitter and receiver. Furthermore, this project will investigate the performance and complexity tradeoffs of anti-blockage approaches.

15. **Cybersecurity Challenges and Pathways in the Context of Connected Vehicle Systems**
(PI: Chandra Bhat); Anticipated end date: December 31, 2017
This project focuses on one specific challenge: improving the security of data flow in VANETs (Vehicle Ad Hoc Networks). VANETs are used for vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication. They represent a class of Mobile Ad Hoc Networks (MANETs), which are distributed, self-organizing communication networks built up from traveling vehicles. VANETs can be utilized for a broad range of safety and non-safety applications. This project will synthesize various attacks/threats that may be encountered by VANETs in the real world, and identify possible countermeasures to eliminate (or at least reduce the intensity of) such threats. We will highlight the limitations of current security measures and demonstrate a real-world application of a new security protocol that overcomes some of the limitations of existing security protocols.

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

While the design of an efficient and reliable routing protocol is central to VANET performance, this is a challenging task because of rapidly changing topology, frequent disconnection, patterned mobility and involved propagation streams. In addition, routing protocol performance varies substantially depending on the density and mobility present in the network, as well as the topography of the test site (e.g., presence of high-rise buildings and trees) and the radio parameters (e.g., carrier frequency, transmission power, and bandwidth). There are three main objectives in protocol design: reliable packet transmission with minimum delay, maximum throughput, and low communication overhead. Most existing routing protocols address only one or two of these objectives. In this project, we propose the use of hybrid techniques (of existing routing protocols) to simultaneously address all three objectives. We will then evaluate the existing and hybrid routing protocols using two areas as test beds: the Austin downtown area (high vehicular traffic with multiple intersections and the presence of high rise buildings) and a stretch of I-35 outside Austin city limits (low to medium traffic density with high vehicular mobility). Note that, due to safety and financial considerations, we will not actually test the many routing protocols directly in the field, but rather simulate the two test beds in open source VANET simulators.

Research Results Disseminated: 20 papers were published and 19 papers are forthcoming in refereed journals based on the research projects associated with D-STOP. Several other papers are in the review process. 57 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).

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:

Undergrad
Lauryn Altena, Isha Deo, Katherine Smith, Maitri Zalawadia, (supervised by Chandra Bhat)
Diego Neri, Jesus Osorio, Rachel Allensworth, Rebecca Hutchinson, Rahul Patel, Hagen Fritz
    (supervised by Stephen Boyles)
Bruno Chiquini, Maximilian Grether (supervised by Jen Duthie)
Cooper Raterink, Cody Scarborough (supervised by Robert Heath)

Grad
Supervised by Chandra Bhat: Sebastian Astroza (PhD), Alice Chu (MS), Qichun Dai (MS), Amanda
    Deering (MS), Felipe Dias (PhD), Subodh Dubey (PhD), Vivek Kumar (MS), 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 (MS), Michael Levin (PhD), Venktesh Pandey (MS), Tarun Rambha (PhD), Cesar Yahia (MS).
Supervised by Jennifer Duthie: Jackson Archer (MS), Itamar Gal (PhD), Patrick Jordan (MS), Hao Pang
    (PhD), Sara Sadeghi (MS).
Supervised by Constantine Caramanis: Dohyung Park (PhD), Xinyang Yi (PhD).
Supervised by Robert Heath: Anum Ali (PhD), Preeti Kumari (MS/PhD), Vutha Va (PhD), Yuyang Wang
    (MS), Enoch Yeh, (MS).
Supervised by Todd Humphreys: Jahshan Bhatti (PhD), Lakshay Narula (MS/PhD), Ken Pesyna (PhD).
Supervised by Sanjay Shakkottai: Tzu-Ling Kan (MS/PhD).
Supervised by Sriram Vishwanath: Hardik Jain (PhD), Subhashini Krishnasamy (PhD).
Supervised by Jeff Andrews: Chang-sik Choi (PhD).
Supervised by Joydeep Ghosh: Rahi Kalantari (PhD), Taewan Kim (PhD), Michael Motro (PhD).

2016 Summer Internship: Four undergrad interns were supported by D-STOP in the third University Transportation Center-Undergraduate Internship (UTC-UI) program hosted at The University of Texas at Austin. The interns were Maximilian Grether, Katherine Smith, Diego Neri (from UT Austin), and Jesus Osorio (from Valparaiso Univ). Each intern participated in a research project related to the D-STOP center, and were assigned to faculty and researchers associated with the Center for Transportation Research. A weekly seminar was held, consisting of lectures by experts in both wireless networking and transportation research, and served as the basis for conversations on research lying at the intersection of these fields.   The interns were also involved in professional development and social activities organized by the student chapters of the Institute of Transportation Engineers and ITS America.

New Student Orientation: The transportation and wireless networking programs welcomed many new graduate students to D-STOP, including a new student orientation, discussion of ongoing D-STOP projects, and faculty/student discussions of how data is fundamentally changing how we think and plan transportation systems.

Education and Workforce Development Results Disseminated:

Dynamic Traffic Assignment Deployment Training Workshops
The Network Modeling Center (NMC) at CTR offered an advanced dynamic traffic assignment (DTA) training workshop in April (DTA 2.0), building from the tools and models introduced in the first workshop (DTA 1.0) in January 2016. DTA is an enormously useful tool already in use in Central Texas for a variety of applications. It allows planners to predict how travelers will shift their routes in response to changes in the roadway system, and how those decisions will affect the congestion we all experience daily. They also had the second offering of DTA 1.0 on June 7, 2016 to train local agency staff in the use of dynamic traffic assignment for forecasting the impacts of projects.

Short Course on Activity-Based Modeling of Spatial and Temporal Patterns of Human Travel Behaviour
Chandra Bhat (along with two faculty colleagues) provided a 1.5-day course on July 9-10, 2016 at Tongji University in Shanghai, China. This course introduced attendees to the activity-based approach to travel behavior analysis, focusing on data-supported transportation planning and operations (D-STOP) opportunities, and a number of unique elements of the activity-based modeling framework that have been implemented in the Los Angeles area and are scheduled to be implemented in the New York area. The unified modeling framework, developed at the Center for Transportation Research (CTR) at The University of Texas at Austin, the Georgia Institute of Technology, the University of California at Santa Barbara, and many other universities worldwide, constitutes a pragmatic and field-tested comprehensive approach that is deeply embedded in the foundations of human behavioral decision-making. The model system, which has been extensively tested and applied in a number of settings, advances the state of the art of activity-travel demand forecasting beyond the daily activity-pattern and tour-based approaches employed in several metropolitan areas. It is a next-generation application platform that offers a more flexible solution to contemporary transportation policy analysis, offers a stronger foundation for meeting current and future model requirements, and can take advantage of new technologies and methods as they emerge.

Dr. Sanjay Shakkottai gave a presentation entitled "Evolution of the Network Architecture for 5G", at an Open Innovation 5G Academic Roundtable of Verizon Technology and Business Leadership on April 11, 2016. This presentation was to the Verizon strategy leadership team (C-level executive, senior VPs and directors), where Sanjay discussed 5G wireless, the role of transportation, and other drivers of 5G technology.

Dr. Humphreys delivered the Hyundai Distinguished Lecture at UC Berkeley on April 25, 2016. The seminar series is a feature of the Hyundai Center of Excellence at UC Berkeley. In his presentation, Dr. Humphreys argued that low-cost and robust centimeter-accurate satellite navigation is possible and is a must-have component of automated vehicle sensor suites. Such a system under development at UT Austin is 100 times more precise than standard GPS and 100 times less expensive than existing precision GPS systems.

Dr. Jennifer Duthie was invited to participate in an expert panel for a special Austin Forum event entitled "Ridesharing: An Austin Town Hall on the Future of Transportation Network Companies (Uber, Lyft, and others)" on April 13, 2016. This special town hall meeting was held before a local election on May 7th in order to objectively explain how transportation networking companies (TNCs) work, the current laws and policies (in Austin, and in other cities), what the election means, and what is likely to happen next for either outcome. The Austin Forum is a monthly community engagement activity bringing together technology leaders, advocates, and the public to learn about important technology topics every month.

Dr. Robert Heath was invited to moderate a panel that discussed the interplay between 5G and automotive systems at the Brooklyn 5G Summit in April 2016. Another panel expert included Gaurav Bansal, Senior Researcher at Toyota Infotechnology Center, and a member of the D-STOP BAC. The panel discussed the future of 5G for the automotive industry and the value of communication and communication infrastructure for vehicle automation, and also debated whether 5G could solve problems that dedicated short-range communication and 4G have left unresolved.

Dr. Jennifer Duthie was called in May to testify on CTR's role in Austin's proposal for the Smart City Challenge at a hearing held by the Texas House of Representative Transportation Subcommittee on Long-term Infrastructure Planning. State Representative Ron Simmons invited Duthie to speak in response to an article she co-authored with Chandra Bhat titled "Texas could be an incubator to solve national transportation problems." In the article, Duthie and Bhat address how researchers and government entities can work together to create an effective transportation model in Austin that can be replicated nationwide.

Dr. Jennifer Duthie was invited to speak about efforts being undertaken in her project entitled "Transportation Data Discovery Environment (TDDE)" at an Open Austin monthly meeting in August 2016. Open Austin is the local Code for America brigade and is interested in opening up public sector data and completing projects that achieve public good with the data. She discussed D-STOP efforts with transportation data (Data Rodeo), and brainstormed ways to collaborate.

Dr. Robert Heath was invited as a panelist for a session on "LTE Advanced Pro" at the IEEE Vehicular Technology Conference (VTC2016-Fall), Montreal, Canada in September 2016. A critical enabler of the smart phone revolution is the wide spread deployment of 4G LTE systems. The panel of academic and industrial experts from both the vendor and carrier community discussed the specific drivers and market needs, the technologies and capabilities, research directions as well as deployment strategies associated with LTE-Advanced Pro. At the same conference, Dr. Heath was also a Keynote Speaker for a Workshop on Cellular Internet of Things - Emerging Trends and Enabling Technologies. The focus of the workshop was on the evolution of cellular technologies to support low-power wide-area Internet of Things (IoT) services, related requirements, commercial use cases, field experiments and performance results.

Plans for Next Reporting Period to Accomplish Education and Workforce Development Goal:
Organize the first board meeting of UT SAVES (Situation-Aware Vehicular Engineering Systems), a new Center directed by Dr. Robert Heath. In partnership with CTR, WNCG has created this Center to address the challenges of wireless, networking, and sensing in vehicular systems. Continue discussions with the Business Advisory Council (BAC), and organize a second BAC meeting along with the 3rd D-STOP Symposium in Spring 2017. Begin organization of the fourth University Transportation Center-Undergraduate Internship (UTC-UI) program to be held the summer of 2017.

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

D-STOP Symposium:
The second D-STOP Symposium on "Smart Cities" was held April 1, 2016. The day-long event explored smart transportation systems, collaborative ecosystems, infrastructure-based technology, regional planning and analytics, and connected vehicles through a series of panels featuring experts in the field. This symposium brought together research being conducted as part of the Data Supported Transportation Operations and Planning (D-STOP) UTC Tier 1 Center and beyond with additional perspectives from individuals in the Industry (associated with automotive manufacturers, wireless communications technology, and intelligent transportation systems) as well as leaders of State Departments of Transportation. In addition, the opportunity for our D-STOP students to meet with, and interact with, leaders in the industry and public government agencies is an important element of D-STOP's education and work force development (EWD) efforts. Please see attached agenda for a full listing of sessions and presentations.

Center for Transportation Research (CTR) Annual Symposium
The annual CTR Symposium was held on April 13, 2016, and was attended by TxDOT staff, as well as representatives from transportation public agencies in the Austin area. CTR staff, faculty, and students were present to discuss ongoing research pursuits. This included D-STOP-related poster presentations made by D-STOP funded students. The focus of this year's symposium was on "Practice", emphasizing tools to improve daily operations as well as practical application of research to create the next generation of engineers. The day's final session was a panel discussion of the USDOT's Smart City Challenge, in which the city of Austin was one of seven finalists. Dr. Mike Walton and Dr. Jen Duthie joined with TxDOT's Director of Strategy and Innovation Darran Anderson for this overview of Austin's participation in this challenge, highlighting CTR's role in the proposal, which is to create and host a Data Rodeo. The Data Rodeo will be a single point of access for regional transportation data and analytics.

Innovations in Travel Modeling (ITM) conference
Dr. Jennifer Duthie co-organized the 6th biennial Innovations in Travel Modeling (ITM) Conference, held in Denver, Colorado in May 2016. This conference, sponsored by the Transportation Research Board, allowed researchers and practitioners to share knowledge and experiences on cutting-edge travel modeling.

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

Published:

Bhat, C.R., S. Astroza, and A.C. Bhat (2016). "On Allowing a General Form for Unobserved Heterogeneity in the Multiple Discrete-Continuous Probit Model: Formulation and Application to Tourism Travel." *Transportation Research Part B*, 86, 223-249.

Bhat, C.R., S. Astroza, A.C. Bhat, and K. Nagel (2016). "Incorporating a Multiple Discrete-Continuous Outcome in the Generalized Heterogeneous Data Model: Application to Residential Self-Selection Effects Analysis in an Activity Time-use Behavior Model." *Transportation Research Part B*, 91, 52-76.

Levin, M. W., and S. D. Boyles (2016). Improving Bus Routing for KIPP Charter Schools. *Interfaces* 46, 196-199.

Levin, M. W., and S. D. Boyles (2016). A Cell Transmission Model for Dynamic Lane Reversal with Autonomous Vehicles. *Transportation Research Part C* 68, 126-143.

Boyles, S. D., and T. Rambha (2016). A Note on Detecting Unbounded Instances of the Online Shortest Path Problem. *Networks* 31, 86-99.

Levin, M. W., R. Patel, and S. D. Boyles. (2016) Paradoxes of Reservation-based Intersection Controls in Traffic Networks. *Transportation Research Part A* 90, 14-25.

Pi, Z., J. Choi, and R. W. Heath Jr. (2016). "Millimeter-wave Gbps Broadband Evolution towards 5G: Fixed Access and Backhaul." *IEEE Communications Magazine*, 54(4), 138-144, Apr. 2016.

Choi, J., J. Mo, and R. W. Heath Jr. (2016). "Near Maximum-Likelihood Detector and Channel Estimator for Uplink Multiuser Massive MIMO Systems with One-Bit ADCs." *IEEE Transactions on Communications*, 64(5), 2005-2018.

Heath, Jr., R.W., N. González Prelcic, S. Rangan, W. Roh, and A. Sayeed (2016). "An Overview of Signal Processing Techniques for Millimeter Wave MIMO Systems." *IEEE Journal of Selected Topics in Signal Processing*, 10(3), 436-453.

Va, V., T. Shimizu, G. Bansal, and R.W. Heath, Jr. (2016). "Beam Design for Beam Switching Based Millimeter Wave Vehicle-to-Infrastructure Communications." *Proceedings of the 2016 IEEE International Conference on Communications (ICC)*, Kuala Lumpur, Malaysia, May.

Banerjee, S., S. Sanghavi and S. Shakkottai (2016). "Online Collaborative-Filtering on Graphs". *Operations Research (INFORMS), Special Issue on Information and Decisions in Social and Economic Networks,* 64(3), 756-769.

Ray, S. Sanghavi and S. Shakkottai (2016). "Searching for A Single Community in a Graph". *Proceedings of ACM Sigmetrics* (poster paper), Antibes Juan-Les-Pins, France, June 2016.

Krishnasamy, S., R. Sen. S. Oh and S. Shakkottai (2016). "Detecting Sponsored Recommendations". *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS),* 2016.

Ghaderi, J., S. Shakkottai and R. Srikant (2016). "Scheduling Storms and Streams in the Cloud". *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS),* 1(4), September 2016.

Narula, L., and T. E. Humphreys (2016). "Requirements for secure wireless time transfer." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 874-886.

Murrian, M., C. Gonzalez, T.E. Humphreys, and T.D. Novlan (2016). "A dense reference network for mass-market centimeter-accurate positioning." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 243-254.

Humphreys, T.E., M. Murrian, K. M. Pesyna, Jr., F. van Diggelen, and S. Podshivalov (2016). "On the feasibility of centimeter-accurate positioning via a smartphones antenna and GNSS chip." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 232 - 242.

Psiaki, M.L., and T.E. Humphreys (2016). "GNSS Spoofing and Detection." *Proceedings of the IEEE*, 104(6), 1258-1270, June.

Psiaki, M.L., T.E. Humphreys and B. Stauffer (2016). "Attackers can spoof navigation signals without our knowledge. Here's how to fight back GPS lies," *IEEE Spectrum*, 53(8), 26-53, August.

Murrian, M.J., C.W. Gonzalez, T.E. Humphreys, K.M. Pesyna, Jr, D.P. Shepard, and A.J. Kerns, (2016). "Low-Cost Precise Positioning for Automated Vehicles." *GPS World*, 27(9), 32-39, September.

Forthcoming:

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

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

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," forthcoming, *IEEE Communications Magazine*.

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

Lavieri, P., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Introducing Latent Psychological Constructs in Injury Severity Modeling: A Multi-Vehicle and Multi-Occupant Approach." *Transportation Research Record*, forthcoming.

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,* 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., H. Fritz, and S. D. Boyles. On optimizing reservation-based intersection controls. *IEEE Transactions on Intelligent Transportation Systems*, forthcoming

Rambha, T., and S.D. Boyles (2016), "Dynamic Pricing in Discrete Time Stochastic Day-to-Day Route Choice Models." *Transportation Research Part B*, forthcoming.

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

Duell, M., M.W. Levin, S.D. Boyles, and S.T. Waller. The impact of autonomous vehicles on traffic management: the case of dynamic lane reversal. *Transportation Research Record*, forthcoming.

Va, V., H. Vikalo, and R. W. Heath Jr., "Beam tracking for mobile millimeter wave communications systems," to appear in *Proceedings of the IEEE GlobalSIP*, Dec. 2016.

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

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

Ali, A., N. González Prelcic, and R.W. Heath, Jr., "Estimating Millimeter Wave Channels using Out-of-Band Measurements," to appear in *Proceedings of Information Theory and Applications (ITA) Workshop*, San Diego, California, January 31 - February 5, 2016.

González Prelcic, N., R. Méndez-Rial, and R.W. Heath, Jr., "Radar Aided Beam Alignment in MmWave V2I Communications Supporting Antenna Diversity, '' to appear in *Proceedings of Information Theory and Applications (ITA) Workshop*, San Diego, California, January 31 - February 5, 2016.

Moharir, S., S. Krishnasamy and S. Shakkottai, "Scheduling in Densified Networks: Algorithms and Performance". *IEEE/ACM Transaction on Networking*, 2016, forthcoming

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

Bhatti, J. and T. Humphreys, "Hostile control of ships via false GPS signals: Demonstration and detection." *Navigation, Journal of the Institute of Navigation*, forthcoming.

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

Bhat, C.R., "Predictive Analytics for Transportation in a High Dimensional Heterogeneous Data World," *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

Boyles, S.D., "Looking to the Future: Predictions of automated vehicle impacts." *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

Perrine, K., M.W. Levin, M. Duell, and S.D. Boyles. "Implications of traffic signal security on potential deliberate traffic disruptions." Poster presented at the *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

Chu, A., M. Motro, J. Choi, 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." Poster presented at the *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

Bhat, C.R., S. Astroza, A.C. Bhat, and K. Nagel, "Incorporating a Multiple Discrete-Continuous Outcome in the Generalized Heterogeneous Data Model: Application to Residential Self-Selection Effects Analysis in an Activity Time-use Behavior Model." Poster presented at the *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

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James, R., E. Jafai, J. Archer, M.D. Gemar, and N. Ruiz Juri, "Using Parcel Data to Inform Centroid Connector Placement." Poster presented at the *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

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Kumari, P., N.G. Prelcic, J. Choi, and R. W. Heath Jr., "IEEE 802.11ad V2X-Radar: A Joint Millimeter-Wave Vehicular Communication and Radar System," Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2016.

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Bhat, C.R., "Cause-Effect Relationships in Residential, Auto Ownership and Activity Choices," *Invited Seminar*, Department of Civil Engineering, Indian Institute of Technology (IIT) Bombay, Mumbai, India, April 2016.

Bhat, C.R., "Activity-Based Modeling: Recent Advances and Possible Application to the Calicut Region," *Invited Seminar*, Department of Civil Engineering, National Institute of Technology (NIT) Calicut, Calicut, India, April 2016.

Bhat, C.R., "Social Interactions in an Integrated Model of Residential Choice and Activity-Travel Choices," *Invited Seminar*, Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Hong Kong, April 2016.

Humphreys, T.E., M. Murrian, F. van Diggelen, S. Podshivalov, and K.M. Pesyna, Jr., "On the feasibility of centimeter-accurate positioning via a smartphones antenna and GNSS chip." *IEEE/ION PLANS 2016 Meeting*, Savannah, GA, April 2016.

Narula, L., and T. E. Humphreys, "Requirements for secure wireless time transfer." *IEEE/ION PLANS 2016 Meeting*, Savannah, GA, April 2016.

Murrian, M., C.W. Gonzalez, T.E. Humphreys, and T.D. Novlan, "A dense reference network for mass-market centimeter-accurate positioning." *IEEE/ION PLANS 2016 Meeting*, Savannah, GA, April 2016.

Humphreys, T.E., "Low Cost Precise Positioning for Automated Vehicles." Distinguished Lecture, *Hyundai Center of Excellence Seminar Series*, UC Berkeley, Berkeley, CA, April 2016

Duthie, J. "Data Rodeo." *MetroLab Network Spring Summit*, San Diego, CA, May 2016.

Gemar, M., N. Ruiz Juri, J. Duthie, K. Perrine, G. Abram, R. Dooley, "Accelerating the Impact of Data in Transportation Modeling Through Cyber Infrastructure," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Gemar, M., J. Duthie, A. Khani, J. Archer, N. Ruiz Juri, and K. Perrine, "Integrated Dynamic Traffic and Transit Assignment for a Multimodal Corridor Study," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Bhat, C.R., "Promoting and Accelerating Collaboration Between Academia and the Practicing Profession: Opportunities and Pathways Forward," Keynote Presentation, *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Bhat, C.R., S. Astroza, S.R. Jara-Diaz, and A.R. Pinjari, "A Latent Class Multiple Constraint Multiple Discrete-Continuous Extreme Value Model of Time Use and Goods Consumption," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Bhat, C.R., "Connected and Automated Cars: Challenges and the Road Ahead," *Invited Seminar*, Transport Research Centre, Universidad Politecnica de Madrid, Madrid, Spain, May 2016.

Bhat, C.R., "Connected and Automated Vehicles (CAVs): Implications for Travel and Infrastructure Provision," *Invited Seminar*, Business Development Workshop, Ferrovial Corporate University, Madrid, Spain, May 2016.

Bhat, C.R., "On Accommodating Spatial Interactions in an Integrated Model of Mixed Types of Dependent Variables," *Academy Colloquium on Spatial Behavior and Crime: Theories, Data, Methods, and Applications*, Royal Netherlands Academy of Arts and Sciences (KNAW), Amsterdam, The Netherlands, May 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Volpe, The National Transportation Systems Center, Cambridge, MA, May 2016.

Boyles, S. D. (2016) An Overview of Autonomous Vehicle Modeling," *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Duthie, J. "Data Rodeo." *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Duthie, J. "Data Rodeo." *Smart Cities Innovation Summit*, Austin, TX, June 2016.

Levin, M., S. D. Boyles, and T. Rambha. (2016) Pressure-based policies for reservation-based intersection control. *6th International Symposium on Dynamic Traffic Assignment (DTA2016)*, Sydney, Australia, June 2016.

Ruiz Juri, N., M. Gemar, K. Perrine, and J. Duthie. "Bringing DTA innovation into practice: Research needs and the role of data and cyberinfrastructure." *6th International Symposium on Dynamic Traffic Assignment (DTA2016)*, Sydney, Australia, June 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Centre for Transport Studies, University College London (UCL), London, UK, June 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *Invited Seminar*, Transport Research Institute, Edinburgh Napier University, Edinburgh, UK, June 2016.

Bhat, C.R., "General Introduction to Choice Modeling," Tutorial Session, Urban Big Data Centre, University of Glasgow, Glasgow, UK, June 2016.

Bhat, C.R., S. Astroza, A.C. Bhat, and K. Nagel, "Cause-Effect Relationships in Residential, Auto Ownership, and Activity Choices," *Invited Seminar*, Urban Big Data Centre, University of Glasgow, Glasgow, UK, June 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Dublin, Ireland, June 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Sharon, G., J. Hanna, T. Rambha, M. Albert, P. Stone, and S. D. Boyles. (2016) Delta-tolling: adaptive tolling for optimizing traffic throughput. *9th International Workshop on Agents in Traffic and Transportation (ATT 2016)*, New York, NY, July 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *16th COTA International Conference of Transportation Professionals (CICTP2016)*, Shanghai, China, July 2016.

Bhat, C.R., R. Pendyala, and K. Goulias, "Activity-Based Modeling of Spatial and Temporal Patterns of Human Travel Behaviour," *Executive Short Course*, Tongji University, Shanghai, China, July 2016.

Astroza, S., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, P. Lavieri, and F.F. Dias, "Analysis of the Impact of Technology Use on Multi-Modality and Activity-Travel Characteristics," *International Workshop on ICT, Activities, Time Use and Travel*, Nanjing, China, July 2016.

Dockstader, D., C.R. Bhat, T. O'Brien, "Getting the Most Out of the DOT-UTC Relationship: Research Design, Contract Management and Leveraging Resources," *2016 AASHTO RAC and TRB State Representatives Summer Meetings*, Providence, RI, July 2016.

Levin, M. W., H. Smith, and S. D. Boyles. (2016) An Assessment of Autonomous Vehicles: Traffic impacts and infrastructure needs. *Smart Transport Symposium*, UT Austin, August 2016.

Shimizu, T. and R. W. Heath Jr., "Millimeter Wave communication for connected vehicles." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Va, V. and R. W. Heath Jr., "Performance Analysis of Beam Sweeping in Millimeter Wave Assuming Noise and Imperfect Antenna Patterns." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Wang, Y., K. Venugopal, A. F. Molisch and R. W. Heath Jr., "Analysis of Urban Millimeter Wave Microcellular Networks." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," Keynote Presentation, Workshop on Cellular Internet of Things - Emerging Trends and Enabling Technologies, *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," Keynote Presentation, 2016 Tyrrhenian International Workshop on Digital Communications (TIW16) on What Lies Beyond 5G?, Livorno, Italy, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," *Invited Seminar*, Dept of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA, September 2016.

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 presentations regarding connected vehicles during 2016 Texas Wireless Summit to be held October 18, 2016 at UT Austin. The Texas Wireless Summit (TWS) is hosted by the Wireless Networking and Communications Group (WNCG), Dept of Electrical and Computer Engineering. Organize the 3rd Data Supported Transportation Operations and Planning (D-STOP) Symposium to be held in Spring 2017. Organize a Center for Transportation Research (CTR) Symposium to be held in Spring 2017.

2. PRODUCTS

Publications, conference papers, and presentations:

Journal Publications - Published

Bhat, C.R., S. Astroza, and A.C. Bhat (2016). "On Allowing a General Form for Unobserved Heterogeneity in the Multiple Discrete-Continuous Probit Model: Formulation and Application to Tourism Travel." *Transportation Research Part B*, 86, 223-249.

Bhat, C.R., S. Astroza, A.C. Bhat, and K. Nagel (2016). "Incorporating a Multiple Discrete-Continuous Outcome in the Generalized Heterogeneous Data Model: Application to Residential Self-Selection Effects Analysis in an Activity Time-use Behavior Model." *Transportation Research Part B*, 91, 52-76.

Levin, M. W., and S. D. Boyles (2016). Improving Bus Routing for KIPP Charter Schools. *Interfaces* 46, 196-199.

Levin, M. W., and S. D. Boyles (2016). A Cell Transmission Model for Dynamic Lane Reversal with Autonomous Vehicles. *Transportation Research Part C* 68, 126-143.

Boyles, S. D., and T. Rambha (2016). A Note on Detecting Unbounded Instances of the Online Shortest Path Problem. *Networks* 31, 86-99.

Levin, M. W., R. Patel, and S. D. Boyles. (2016) Paradoxes of Reservation-based Intersection Controls in Traffic Networks. *Transportation Research Part A* 90, 14-25.

Pi, Z., J. Choi, and R. W. Heath Jr. (2016). "Millimeter-wave Gbps Broadband Evolution towards 5G: Fixed Access and Backhaul." *IEEE Communications Magazine*, 54(4), 138-144, Apr. 2016.

Choi, J., J. Mo, and R. W. Heath Jr. (2016). "Near Maximum-Likelihood Detector and Channel Estimator for Uplink Multiuser Massive MIMO Systems with One-Bit ADCs." *IEEE Transactions on Communications*, 64(5), 2005-2018.

Heath, Jr., R.W., N. González Prelcic, S. Rangan, W. Roh, and A. Sayeed (2016). "An Overview of Signal Processing Techniques for Millimeter Wave MIMO Systems." *IEEE Journal of Selected Topics in Signal Processing*, 10(3), 436-453.

Va, V., T. Shimizu, G. Bansal, and R.W. Heath, Jr. (2016). "Beam Design for Beam Switching Based Millimeter Wave Vehicle-to-Infrastructure Communications." *Proceedings of the 2016 IEEE International Conference on Communications (ICC)*, Kuala Lumpur, Malaysia, May.

Banerjee, S., S. Sanghavi and S. Shakkottai (2016). "Online Collaborative-Filtering on Graphs". *Operations Research (INFORMS), Special Issue on Information and Decisions in Social and Economic Networks,* 64(3), 756-769.

Ray, S. Sanghavi and S. Shakkottai (2016). "Searching for A Single Community in a Graph". *Proceedings of ACM Sigmetrics* (poster paper), Antibes Juan-Les-Pins, France, June 2016.

Krishnasamy, S., R. Sen. S. Oh and S. Shakkottai (2016). "Detecting Sponsored Recommendations". *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS),* 2016.

Ghaderi, J., S. Shakkottai and R. Srikant (2016). "Scheduling Storms and Streams in the Cloud". *ACM Transactions on Modeling and Performance Evaluation of Computing Systems (ACM ToMPECS),* 1(4), September 2016.

Narula, L., and T. E. Humphreys (2016). "Requirements for secure wireless time transfer." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 874-886.

Murrian, M., C. Gonzalez, T.E. Humphreys, and T.D. Novlan (2016). "A dense reference network for mass-market centimeter-accurate positioning." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 243-254.

Humphreys, T.E., M. Murrian, K. M. Pesyna, Jr., F. van Diggelen, and S. Podshivalov (2016). "On the feasibility of centimeter-accurate positioning via a smartphones antenna and GNSS chip." *Proceedings of the IEEE/ION Position, Location and Navigation Symposium (PLANS) 2016 Meeting*, Savannah, GA, April, pp. 232 - 242.

Psiaki, M.L., and T.E. Humphreys (2016). "GNSS Spoofing and Detection." *Proceedings of the IEEE*, 104(6), 1258-1270, June.

Psiaki, M.L., T.E. Humphreys and B. Stauffer (2016). "Attackers can spoof navigation signals without our knowledge. Here's how to fight back GPS lies," *IEEE Spectrum*, 53(8), 26-53, August.

Murrian, M.J., C.W. Gonzalez, T.E. Humphreys, K.M. Pesyna, Jr, D.P. Shepard, and A.J. Kerns, (2016). "Low-Cost Precise Positioning for Automated Vehicles." *GPS World*, 27(9), 32-39, September.

Presentations

Bhat, C.R., "Predictive Analytics for Transportation in a High Dimensional Heterogeneous Data World," *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

Boyles, S.D., "Looking to the Future: Predictions of automated vehicle impacts." *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, April 2016.

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Murrian, M., C.W. Gonzalez, T.E. Humphreys, and T.D. Novlan, "A dense reference network for mass-market centimeter-accurate positioning." *IEEE/ION PLANS 2016 Meeting*, Savannah, GA, April 2016.

Humphreys, T.E., "Low Cost Precise Positioning for Automated Vehicles." Distinguished Lecture, *Hyundai Center of Excellence Seminar Series*, UC Berkeley, Berkeley, CA, April 2016

Duthie, J. "Data Rodeo." *MetroLab Network Spring Summit*, San Diego, CA, May 2016.

Gemar, M., N. Ruiz Juri, J. Duthie, K. Perrine, G. Abram, R. Dooley, "Accelerating the Impact of Data in Transportation Modeling Through Cyber Infrastructure," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Gemar, M., J. Duthie, A. Khani, J. Archer, N. Ruiz Juri, and K. Perrine, "Integrated Dynamic Traffic and Transit Assignment for a Multimodal Corridor Study," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

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Bhat, C.R., S. Astroza, S.R. Jara-Diaz, and A.R. Pinjari, "A Latent Class Multiple Constraint Multiple Discrete-Continuous Extreme Value Model of Time Use and Goods Consumption," *Innovations in Travel Modeling Conference*, Denver, CO, May 2016.

Bhat, C.R., "Connected and Automated Cars: Challenges and the Road Ahead," *Invited Seminar*, Transport Research Centre, Universidad Politecnica de Madrid, Madrid, Spain, May 2016.

Bhat, C.R., "Connected and Automated Vehicles (CAVs): Implications for Travel and Infrastructure Provision," *Invited Seminar*, Business Development Workshop, Ferrovial Corporate University, Madrid, Spain, May 2016.

Bhat, C.R., "On Accommodating Spatial Interactions in an Integrated Model of Mixed Types of Dependent Variables," *Academy Colloquium on Spatial Behavior and Crime: Theories, Data, Methods, and Applications*, Royal Netherlands Academy of Arts and Sciences (KNAW), Amsterdam, The Netherlands, May 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Volpe, The National Transportation Systems Center, Cambridge, MA, May 2016.

Boyles, S. D. (2016) An Overview of Autonomous Vehicle Modeling," *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Duthie, J. "Data Rodeo." *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Duthie, J. "Data Rodeo." *Smart Cities Innovation Summit*, Austin, TX, June 2016.

Levin, M., S. D. Boyles, and T. Rambha. (2016) Pressure-based policies for reservation-based intersection control. *6th International Symposium on Dynamic Traffic Assignment (DTA2016)*, Sydney, Australia, June 2016.

Ruiz Juri, N., M. Gemar, K. Perrine, and J. Duthie. "Bringing DTA innovation into practice: Research needs and the role of data and cyberinfrastructure." *6th International Symposium on Dynamic Traffic Assignment (DTA2016)*, Sydney, Australia, June 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Centre for Transport Studies, University College London (UCL), London, UK, June 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *Invited Seminar*, Transport Research Institute, Edinburgh Napier University, Edinburgh, UK, June 2016.

Bhat, C.R., "General Introduction to Choice Modeling," Tutorial Session, Urban Big Data Centre, University of Glasgow, Glasgow, UK, June 2016.

Bhat, C.R., S. Astroza, A.C. Bhat, and K. Nagel, "Cause-Effect Relationships in Residential, Auto Ownership, and Activity Choices," *Invited Seminar*, Urban Big Data Centre, University of Glasgow, Glasgow, UK, June 2016.

Bhat, C.R., "Connected and Automated Cars: What They Can and May Do to Our Way of Life," *Invited Seminar*, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Dublin, Ireland, June 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *D-STOP Undergraduate Summer Internship Faculty Presentations*, UT Austin, June 2016.

Sharon, G., J. Hanna, T. Rambha, M. Albert, P. Stone, and S. D. Boyles. (2016) Delta-tolling: adaptive tolling for optimizing traffic throughput. *9th International Workshop on Agents in Traffic and Transportation (ATT 2016)*, New York, NY, July 2016.

Bhat, C.R., "Predictive Analytics for Transportation Planning and Operations in a World of Big Data," *16th COTA International Conference of Transportation Professionals (CICTP2016)*, Shanghai, China, July 2016.

Bhat, C.R., R. Pendyala, and K. Goulias, "Activity-Based Modeling of Spatial and Temporal Patterns of Human Travel Behaviour," *Executive Short Course*, Tongji University, Shanghai, China, July 2016.

Astroza, S., V.M. Garikapati, C.R. Bhat, R.M. Pendyala, P. Lavieri, and F.F. Dias, "Analysis of the Impact of Technology Use on Multi-Modality and Activity-Travel Characteristics," *International Workshop on ICT, Activities, Time Use and Travel*, Nanjing, China, July 2016.

Dockstader, D., C.R. Bhat, T. O'Brien, "Getting the Most Out of the DOT-UTC Relationship: Research Design, Contract Management and Leveraging Resources," *2016 AASHTO RAC and TRB State Representatives Summer Meetings*, Providence, RI, July 2016.

Levin, M. W., H. Smith, and S. D. Boyles. (2016) An Assessment of Autonomous Vehicles: Traffic impacts and infrastructure needs. *Smart Transport Symposium*, UT Austin, August 2016.

Shimizu, T. and R. W. Heath Jr., "Millimeter Wave communication for connected vehicles." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Va, V. and R. W. Heath Jr., "Performance Analysis of Beam Sweeping in Millimeter Wave Assuming Noise and Imperfect Antenna Patterns." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Wang, Y., K. Venugopal, A. F. Molisch and R. W. Heath Jr., "Analysis of Urban Millimeter Wave Microcellular Networks." *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," Keynote Presentation, Workshop on Cellular Internet of Things - Emerging Trends and Enabling Technologies, *IEEE Vehicular Technology Conference (VTC2016-Fall)*, Montreal, Canada, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," Keynote Presentation, 2016 Tyrrhenian International Workshop on Digital Communications (TIW16) on What Lies Beyond 5G?, Livorno, Italy, September 2016.

Heath Jr., R.W., "Vehicle-to-X Communication using Millimeter Waves," *Invited Seminar*, Dept of Electrical and Computer Engineering, University of Virginia, Charlottesville, VA, September 2016.

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
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
University of Southern California, Department of Electrical Engineering - Andreas F. Molisch: Technical consultancy

Have other collaborators or contacts been involved?
Established relations with FR8 Revolution, a Bay Area startup focusing on an online freight marketplace. The relationship includes sharing of anonymized data from the company, and sharing of algorithms and ideas by UT faculty.

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 are introducing psychometric measures of human behavior in characterizing transportation decisions of individuals, and using the resulting insights to drive transportation policy measures and system design.

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. Providing opportunities for our student to be prepared to communicate orally as well as in writing through presentations at conference and publications.

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 feedback will help D-STOP further contribute to societal problems.

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.

Symposium Agenda

7:30 AM - 8:00 AM:	Breakfast at the Symposium Venue
8:00 AM - 8:05 AM:	**Welcome** (Chandra Bhat)
8:05 AM - 9:00 AM:	**"Smart Transportation Systems: The Need for a Collaborative Ecosystem"** (Moderator: Chandra Bhat)

- Gaurav Bansal, Senior Researcher, Toyota InfoTechnology Center
- C. Michael Walton, Ernest H. Cockrell Centennial Chair in Engineering, Dept. of Civil, Architectural & Environmental Engineering, UT Austin
- Sherri Greenberg, Clinical Professor, Fellow of Max Sherman Chair in State and Local Government, LBJ School of Public Affairs, UT Austin
- Jim Dale, PE, Division Manager, Arterial Management Division, City of Austin
- J.D. Stanley, Global Director, Strategy and Integrated Solutions, Cisco

9:00 AM - 10:30 AM:	**"Infrastructure-based Technology"** (Moderator: Robert Heath)

- **The Value of Communication and Infrastructure for Automated Cars**
  Robert Heath, Cullen Trust Endowed Professor, UT Austin
- **Infrastructure for Instantaneous Precise Positioning**
  Todd Humphreys, Associate Professor, Dept. of Aerospace Engineering and Engineering Mechanics, UT Austin
- **Internet of Moving Things using Full Duplex Mesh Networks**
  Sriram Vishwanath, Professor, Electrical and Computer Engineering Dept., UT Austin
- **The Connected Car: Impact on Wireless Communication**
  Murali Narasimha, Wireless Communications Researcher, FutureWei Technologies (Huawei)

10:30 AM - 10:45 AM:	Break
10:45 AM - 12:15 PM:	**"Regional Planning and Analytics"** (Moderator: Jennifer Duthie)

- **Data Rodeo: A Data Analytics Environment for the Central Texas Region**
  Jennifer Duthie, Director, Network Modeling Center, UT Austin
- **Predictive Analytics for Transportation in a High Dimensional Heterogeneous Data World**
  Chandra Bhat, Director of D-STOP and CTR, and the Adnan Abou-Ayyash Centennial Professor in Transportation Engineering, UT Austin
- **Planning for the Future in a Changing Environment**
  Arash Mirzaei, Senior Program Manager for Model Development and Data Management, North Central Texas Council of Governments
- **Using Publicly Available Datasets to Evaluate the Intersection between Bicycling and Commercial Vehicles**
  Alison Conway, Assistant Professor at City College of New York

12:15 pm - 1:30 pm:	Networking Lunch
1:30 pm - 3:00 pm:	**"Connected Vehicles"** (Moderator: Stephen Boyles)

- **Connected Automation: Two Technologies That Need Each Other**
  Paul Avery, Principal Engineer, Cooperative Systems Section, Southwest Research Institute
- **Looking to the Future: Predictions of Automated Vehicle Impacts**
  Stephen Boyles, Assistant Professor, Dept. of Civil, Architectural & Environmental Engineering, UT Austin
- **Connecting Capital Metro**
  Joe Iannello, Vice President, Chief Information Officer, Capital Metro
- **Networks of Wearables and Augmented Reality for Vulnerable User Protection**
  Christian Claudel, Assistant Professor, Dept. of Civil, Architectural & Environmental Engineering, UT Austin

3:00 pm - 3:30 pm:	**General discussions and wrap-up presentation** (WNCG Director Sanjay Shakkottai)
3:30 pm - 4:30 pm:	**Poster session** in the courtyard. Soft drinks and cookies provided.