Program Progress Performance Report

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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 18 projects were pursued with partial or full funding support from D-STOP. Of these, three projects were completed during this reporting period. Currently, 15 projects are underway.

Completed Projects

1. **An Empirical Investigation into the Time-Use and Activity Patterns of Dual-Earner Couples With and Without Young Children**
   (PI: Chandra Bhat); End date: September 30, 2015
   This proposal examines the time-use patterns of adults in dual-earner households with and without children as a function of several individual and household socio-demographics and employment characteristics. A disaggregate activity purpose classification including both in-home and out-of-home activity pursuits will be used because of the travel demand relevance of out-of-home pursuits, as well as to examine both mobility-related and general time-use related social exclusion and time poverty issues. The study uses the Nested Multiple Discrete Continuous Extreme Value (MDCNEV) model, which recognizes that time-decisions entail the choice of participating in one or more activity purposes along with the amount of time to invest in each chosen activity purpose, and allows generic correlation structures to account for common unobserved factors that might impact the choice of multiple alternatives. The 2010 American Time Use Survey (ATUS) data is used for the empirical analysis.

2. **A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables**
   (PI: Chandra Bhat); End date: September 30, 2015
   This proposal formulates a generalized heterogeneous data model (GHDM) that jointly handles mixed types of dependent variables—including multiple nominal outcomes, multiple ordinal variables, and multiple count variables, as well as multiple continuous variables—by representing the covariance relationships among them through a reduced number of latent factors. Sufficiency conditions for identification of the GHDM parameters are presented. The maximum approximate composite marginal likelihood (MACML) method is proposed to estimate this jointly mixed model system. This estimation method provides computational time advantages since the dimensionality of integration in the likelihood function is independent of the number of latent factors. The study undertakes a simulation experiment within the virtual context of integrating residential location choice and travel behavior to evaluate the ability of the MACML approach to recover parameters.

3. **A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation**
   (PI: Chandra Bhat); End date: September 30, 2015
   This proposal formulates a model that extends the traditional panel discrete choice model to include social/spatial dependencies in the form of dyadic interactions between each pair of decision-makers. In addition, the formulation accommodates spatial correlation effects as well as allows a global spatial structure to be placed on the individual-specific unobserved response sensitivity to exogenous variables. We interpret these latter two effects, sometimes referred to as spatial drift effects, as originating from endogenous group formation. To our knowledge, we are the first to suggest this endogenous group formation interpretation for spatial drift effects in the social/spatial interactions literature. The formulation is motivated in a travel mode choice context, but is applicable in a wide variety of other empirical contexts.

Ongoing Projects

1. **Cell Phone Data for Travel Forecasting**
   (PI: Jennifer Duthie); Anticipated end date: December 31, 2015
   Little guidance exists on how to calibrate and validate planning models with anything except for very aggregate count data. With more data available than ever before, guidance is needed on how to calibrate and validate models that take advantage of this data. This project will focus on origin-destination trip matrix data aggregated from cell-phone providers. The research team will acquire a dataset, evaluate its validity by comparing it to other data sources, and will report on the potential for the data to be used as input to a transportation planning model.

2. **Transit Demand and Routing after Autonomous Vehicle Availability**
   (PI: Stephen Boyles); Anticipated end date: December 31, 2015
   Autonomous vehicles (AVs) create the potential for improvements in traffic operations as well as new behaviors for travelers such as car sharing among trips through driverless repositioning. Most studies on AVs have focused on technology or traffic operations, and the impact of AVs on planning is currently unknown. Development of a planning model integrating AV improvements to traffic operations and the impact of new traveler behavior options will soon be of practical interest as AVs are currently test-driven on public roads. The altered traveler preferences may affect mode choice, leading to changes in transit demand and transit provider cost. An analysis of the model on metropolitan planning data will provide predictions on the impact of general AV ownership on network conditions.

3. **Semi-Autonomous Parking for Enhanced Safety and Efficiency**
   (PI: Sriram Vishwanath); Anticipated end date: January 15, 2016
   This project focuses on the use of tools from a combination of computer vision and localization based navigation schemes to aid the process of efficient and safe parking of vehicles in high density parking spaces. The principles of collision avoidance, simultaneous localization and mapping together with vision based actuation in robotics will be used to enable this functionality.

4. **Combining Millimeter-Wave Radar and Communication Paradigms for Automotive Applications: A Signal Processing Approach**
(Co-PI: Robert Heath and Chandra Bhat); Anticipated end date: May 31, 2016
This project proposes to develop a conceptual mathematical model for combined paradigm of millimeter-wave communication and radar using a signal processing perspective. In particular, it will explore and investigate different possible signal frameworks for joint communication and radar paradigms, both with simultaneous or non-simultaneous applications. For these mathematical frameworks, novel algorithms will be developed targeting automotive applications. Our algorithms will leverage the performance of the joint paradigm by sharing information between the radar and communications signal frameworks. These algorithms will be further optimized to meet varied performance objectives in both rural and urban areas. This would require identifying the scenarios of interest in transportation environments. A design-trade off analysis will be carried out to meet the conflicting requirements of both the signal frameworks. The outcomes of the project are expected to dramatically improve safety for vehicles, bicycles, and pedestrians in all weather conditions and on all roadways.

5. **Coherence Time and Beam Alignment for mmWave Vehicular Communications**
(PI: Robert Heath); Anticipated end date: October 31, 2015
The goal of this project is to develop a learning based approach to significantly reduce the overhead leveraging side information including user positioning information and network geometry. After initial design, we use offline learning to construct an initial mapping from user feedback to the beam selection. During operation, new data are collected and used to refine the initial mapping. The online learning part can be viewed as a multi-armed bandit (MAB) problem and solved by leveraging the existing results on the subject.

6. **Improved Traffic Operations through Real-Time Data Collection and Control**
(Co-PIs: Stephen Boyles and Sanjay Shakkottai); Anticipated end date: May 31, 2016
New data collection technologies enable real-time traffic control more precise and efficient than what was earlier possible. This project develops novel control strategies based on this data, with an emphasis on two types of traffic control: (1) *signalized intersection* control, where cycle lengths and phasing may be adjusted based on observed demands and coordination with nearby intersections, and (2) *pricing* strategies, where tolls are adjusted in real time based on observed demand, in order to influence travelers to avoid congested areas. Both of these share a common methodological basis of adjusting traffic controls to prioritize particular vehicles to minimize congestion, accounting for human behavior and learning. The project will involve combining wireless routing algorithms with traffic engineering knowledge to create innovative control policies.

7. **Models for High Dimensional Mixed Regression**
(Co-PIs: Constantine Caramanis and Chandra Bhat); Anticipated end date: December 31, 2015
We propose to consider the mixed regression problem in high dimensions, under adversarial and stochastic noise. We will consider convex optimization-based formulations with the aim of showing that it provably recovers the true solution. This agenda will seek to provide upper bounds on the recovery errors for both arbitrary noise and stochastic noise settings. We also will seek matching minimax lower bounds (up to log factors), showing that under certain assumptions, our algorithm is information-theoretically optimal. Our preliminary results represent the first (and currently only known) tractable algorithm guaranteeing successful recovery with tight bounds on recovery errors and sample complexity. Mixture models treat observed data as a superposition of simple statistical processes. Thus they are particularly relevant in the transportation setting, when city-wide phenomena are often mixtures of simple processes (cut-through traffic, intra-city movement, etc.).

8. **Streaming PCA with Many Missing Entries**
(PI: Constantine Caramanis); Anticipated end date: December 31, 2015
We propose to consider the streaming memory-constrained principal component analysis (PCA) problem with missing entries, where the available storage is linear in the dimensionality of the problem, and each vector has so many missing entries that matrix completion is not possible. For this

problem, we propose a method based on a block power update approach introduced in our previous work. We show on synthetic as well as benchmark data sets that our approach outperforms existing approaches for streaming PCA by a significant margin for several interesting problem settings. We also consider the popular spiked covariance model with randomly missing entries, and obtain the first known global convergence guarantees for this problem. We show that our method converges to the true ``spike'' using a number of samples that is linear in the dimension of the data. Moreover, our memory requirement is also linear in the ambient dimension. Thus, both memory and sample complexity have optimal scaling with dimension. Streaming PCA is extremely relevant in the setting where the resolution of our sensors outpaces our ability to store massive amounts of data. This is precisely the setting we face as we increase the amount of intelligence and high precision/resolution sensors on the fleet of private and commercial vehicles.

9. **Greedy Subspace Clustering**
   (PI: Constantine Caramanis); Anticipated end date: September 30, 2016
   We propose to consider the problem of subspace clustering: given points that lie on or near the union of many low-dimensional linear subspaces, recover the subspaces. To this end, one first identifies sets of points close to the same subspace and uses the sets to estimate the subspaces. As the geometric structure of the clusters (linear subspaces) forbids proper performance of general distance based approaches such as K-means, many model-specific methods have been proposed. In this paper, we provide new simple and efficient algorithms for this problem. Our statistical analysis shows that the algorithms are guaranteed exact (perfect) clustering performance under certain conditions on the number of points and the affinity between subspaces. These conditions are weaker than those considered in the standard statistical literature. Experimental results on synthetic data generated from the standard unions of subspaces model demonstrate our theory. We also show that our algorithm performs competitively against state-of-the-art algorithms on real-world applications such as motion segmentation and face clustering, but with much simpler implementation and lower computational cost.

10. **High-precision GPS Vehicle Tracking to Improve Safety**
    (Co-PIs: Jennifer Duthie and Todd Humphreys); Anticipated end date: August 31, 2016
    Commercial Global Positioning System (GPS) devices are being used in transportation for applications including vehicle navigation, traffic monitoring, and tracking commercial and public transit vehicles. The current state-of-practice technology in GPS devices typically has 10-meter accuracy and can properly answer the needs in the above applications. When it comes to safety, where driver behavior is important, new technologies for high-precision (i.e., centimeter-level) mobility detection are required. It is with high-precision GPS traces that safety can be evaluated by identifying when drivers are drowsy or distracted, and anticipating problems before they occur. Through this project, the team will build low-cost high-precision GPS devices, obtain GPS traces by placing the devices on buses, and analyzing the traces to identify driver behavior indicators that could anticipate a safety concern before it occurs.

11. **Infrastructure-Informed Travel Sheds**
    (PI: Jennifer Duthie); Anticipated end date: December 31, 2015
    An infrastructure informed index is needed for pedestrians and bicyclists to relate the natural and built environment with its impact on perceived travel distance and time. The objective is to develop an easy to use metric for use at all levels, allowing transportation planners to make better informed decisions when planning or redeveloping a city or area. Building off of previous research efforts, attributes will be determined and weighted to capture the characteristics of a link, then summed to create the infrastructure informed index for pedestrians and bicyclists, respectively. Pedestrian perception data collected by the PI previously will be used to determine the attributes. The indices will then visualized using ArcGIS mapping tools, creating a service area around specific origin or destination points to see the effective area a pedestrian or bicyclist can travel taking into account the effects of the infrastructure along the route.

12. **The Formulation and Estimation of a Spatial Skew-Normal Generalized Ordered-Response Model**
(PI: Chandra Bhat); Anticipated end date: June 30, 2016
Ordered-response (OR) choice models are now widely used in many different disciplines, including sociology, biology, political science, marketing, and transportation. OR models may be used when analyzing ordinal discrete outcome data that may be considered as manifestations of an underlying scale that is endowed with a natural ordering. In this proposal, we will use the GOR structure as the starting point, and extend the formulation in two different directions. The first direction relates to the distribution of the kernel error distribution, and the second relates to spatial dependence. We will apply the proposed model to examine urban land development intensity levels using parcel-level data from Austin, Texas. The modeling of land-use is an important precursor to understanding the activity-travel behavior of individuals in a region. The primary data will be drawn from the parcel-level land use data sets collected by the City of Austin Watershed Protection and Development Review Department.

13. **A Latent Class Multiple Constraint Multiple Discrete-Continuous Extreme Value Model of Time Use and Goods Consumption**
(PI: Chandra Bhat); Anticipated end date: June 30, 2016
The aim of this proposal is to develop a microeconomic time-use framework that (a) accommodates technological relationships between time allocated to activities and goods consumption, and (b) proposed a discrete distribution for the response coefficients. This latent class model will be able to identify different segments of the population, each one of them with different effects of the exogenous variables on time allocation, activity participation, and goods consumption. This endogenous segmentation will be compared in a comprehensive fashion with the typical segmented estimation of microeconomic time use models (of the type discussed in the first paragraph of this abstract) from a theoretical, conceptual, and empirical data fit standpoint. The empirical analysis will be pursued using a 2012 Dutch data set on weekly time use and good expenditure.

14. **A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation**
(PI: Chandra Bhat); Anticipated end date: December 31, 2015
This proposal adopts a dwelling unit level of analysis and considers a probabilistic choice set generation approach for residential choice modeling. In doing so, we accommodate the fact that housing choices involve both characteristics of the dwelling unit and its location, while also mimicking the search process that underlies housing decisions. In particular, we proposed to model a complete range of dwelling unit choices that include tenure type (rent or own), housing type (single family detached, single family attached, or apartment complex), number of bedrooms, number of bathrooms, number of storeys (one or multiple), square footage of the house, lot size, housing costs, density of residential neighborhood, and commute distance. Bhat's (2014) generalized heterogeneous data model (GHDM) system will be used to accommodate the different types of dependent outcomes associated with housing choices, while capturing jointness caused by unobserved factors. The proposed analytic framework will be applied to study housing choices using data derived from the 2009 American Housing Survey (AHS), sponsored by the Department of Housing and Urban Development (HUD) and conducted by the U.S. Census Bureau

15. **On Accommodating Spatial Interactions in a Generalized Heterogeneous Data Model (GHDM) of Mixed Types of Dependent Variables**
(PI: Chandra Bhat); Anticipated end date: December 31, 2015
Multi-dimensional dependent outcome models are of interest in several fields, including land-use and transportation, biology, finance, and econometrics, just to name a few. The primary motivation for modeling dependent outcomes jointly is that there may be common underlying unobserved factors (attitudes, values, and lifestyle factors) of decision-makers that impact multiple dependent outcomes simultaneously. Even as there has been increasing emphasis on mixed data outcome modeling, there also has been a growing interest in accommodating spatial (and social) dependency effects among decision-makers in mixed data modeling. This is because spatial/social interactions can be exploited by decision-makers to achieve desired system end-states. In the current project, we use the important

insight that the analyst can generate spatial dependence across multiple and mixed outcomes by specifying spatial dependence in the "soft" psychological construct (latent) variables underlying the many outcomes.

Research Results Disseminated: Eight papers were published and nine papers are forthcoming in refereed journals based on the research projects associated with D-STOP. Several other papers are in the review process. Thirty-six 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. Undertake supporting research funded 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

Joseph Gilroy (supervised by by Chandra Bhat)

Rachel Allensworth, Rebecca Hutchinson, Rahul Patel, Tejas Chaudhary, Mark Stahl, Hagen Fritz (supervised by Stephen Boyles)

Bruno Chiquini, Ben Wallach (supervised by Jen Duthie)

Shubodeep Mukherji (supervised by Todd Humphreys)

Bryce Arden, Phillip Lemons, Ryan Meek, Jonathon Reynolds, Kevin Rosen, Robert Syvarth (supervised by Robert Heath)

Grad

Supervised by Chandra Bhat: Swati Agarwal (MS), Sebastian Astroza (PhD), Alice Chu (MS), Amanda Deering (MS), Subodh Dubey (PhD), Vivek Kumar (MS), Patricia Lavieri (PhD).

Supervised by Stephen Boyles: Sudesh Agrawal (MS), John Helsel (MS), Ehsan Jafari (PhD), Rachel James (MS), Michael Levin (PhD), Venktesh Pandey (MS), Tarun Rambha (PhD).

Supervised by Jennifer Duthie: Jackson Archer (MS), Itamar Gal (PhD), Hao Pang (PhD).

Supervised by Constantine Caramanis: Xinyang Yi (PhD), Ioannis Mitliagkas (PhD), Dohyung Park (PhD).

Supervised by Robert Heath: Anum Ali (PhD), Preeti Kumari (MS), Vutha Va (PhD), Enoch Yeh, (MS).

Supervised by Todd Humphreys: Jahshan Bhatti (PhD), Ken Pesyna (PhD).

Supervised by Sanjay Shakkottai: Tzu-Ling Kan (MS).

Supervised by Sriram Vishwanath: Yan Gao (MS).

2015 Summer Internship: Three interns were supported by D-STOP in the second University Transportation Center-Undergraduate Internship (UTC-UI) program hosted at The University of Texas at Austin. The interns were Bruno Chiquini, Joseph Gilroy, and Rahul Patel. 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:

New Undergraduate Course on Data Analysis: Dr. Stephen Boyles introduced a new undergraduate course in spring 2015 titled “Optimization Techniques in Transportation Engineering”. This course provides a survey of optimization and operations research techniques, but placed in the context of transportation engineering and using transportation source problems to motivate and demonstrate these ideas. This course was extremely well-received, with an evaluation of 4.9/5. This course is an upper-division technical elective, typically taken during the senior year, and covers basic linear, nonlinear, and network optimization, with applications in transportation. The PI placed a large emphasis on how to formulate optimization problems, and comparing alternative ways to represent the same engineering problem, a vital skill for students who have learned a number of tools and are beginning to synthesize them for information extraction from data.

Outreach Activities: Dr. Jennifer Duthie gave an introductory lecture on transportation engineering topics and career paths at a GirlStart Summer Camp on June 25, 2015. Girlstart is a community program located in Austin, TX, and their goal is to provide strategies, resources and programs to increase the numbers of young women pursuing education and careers in science, math and engineering. Girlstart Summer Camps are week-long STEM programs for girls entering the 4^{th}-8^{th} grades. These programs achieve consistent positive outcomes by combining formal and informal educational strategies with challenging and relevant STEM curriculum.

Dr. Jennifer Duthie gave a presentation entitled “Driving Around in Circles, The Austin Area Traffic & Transportation Dilemma” on September 12, 2015 to the Austin Branch of the American Association of University Women (AAUW). The mission of AAUW is to advance equity for women and girls through advocacy, education, philanthropy, and research.

Dr. Jennifer Duthie hosted a small follow up meeting on July 6, 2015, after the Integrated Corridor Management -- Data Subcommittee regular meeting, about the opportunities for setting up a data warehouse for regional transportation data at UT Austin.

Dr. Stephen Boyles gave a short course on transportation networks for UT's Honors Colloquium for high school students, July 24, 2015.

Dr. Todd Humphreys was invited by the National PNT Advisory Board to speak at their "GPS toughening" working group meeting on June 10 and then to present before the full Advisory Board on June 11. His presentation concerned GPS navigation message authentication as a means of "toughening" GPS receivers against unintentional and intentional GPS spoofing. As part of the presentation, Humphreys offered a categorization and an ordering of spoofing attacks and defenses that will be a good starting point for a proper civil GPS threat assessment.

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 to constitute Business Advisory Council (BAC) and hold BAC meeting along with the 2^{nd} D-STOP Symposium in Spring 2016. Begin organization of the third University Transportation Center-Undergraduate Internship (UTC-UI) program to be held the summer of 2016.

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

Center for Transportation Research (CTR) Annual Symposium

A CTR Symposium was held on April 8, 2015, at which D-STOP activities were highlighted. The symposium 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 many D-STOP-related poster presentations made by D-STOP funded students. The event was attended by the UT-Austin Cockrell Engineering School Dean, Dr. Sharon Wood. CTR's and D-STOP's roles in enhancing the transportation workforce and stimulating innovation throughout all areas of transportation were emphasized by the D-STOP Director, Prof. Chandra Bhat. In Bhat's own words, "…we now have a renewed emphasis on the notion that collaboration across disciplines and across organizations has intrinsic value and should be viewed as a precursor to innovation rather than the more traditional idea that innovation starts in a certain siloed space and collaboration is simply a vehicle to bring innovation to fruition. An example is the strong collaboration we have developed in the past two years with the wireless and networking group in the Electrical and Computer Engineering Department, and the Computer Science group in the School of Natural Sciences, thanks to the USDOT Tier 1 Data Supported Transportation Operations and Planning (D-STOP) Center here at UT-Austin." The Symposium's theme, consistent with one of D-STOP's focus areas, was "Safety First; Keep 'em Rolling". In addition to researchers, there was also a presentation from the Director of HEB transportation (HEB is a large grocery chain in Texas), which further reinforced how data science and technology efforts have improved safety and economic competitiveness. D-STOP's Jen Duthie also made a formal podium presentation at the symposium discussing the role of data analysis in reducing traffic congestion and delays.

Secretary Foxx Visit

The Center hosted US Secretary of Transportation Anthony Foxx on his national tour of University Transportation Centers (UTC). During his April 24 visit, Secretary Foxx met with D-STOP faculty, researchers, and graduate students, as well as TxDOT, MPO, and industry leadership, at the TACC's Visualization Laboratory (VisLab). As part of the day's roundtable discussion, Foxx learned of D-STOP's program exploring the interface of high-dimensional data management and analysis, wireless-related cybersecurity issues, connected vehicles research challenges and implementation, and real-time information provision. Following the roundtable discussion, Foxx was given a tour of the VisLab, with D-STOP wireless networking and transportation researchers presenting visualizations of wireless networking and GPS applications, cyber-security considerations, transportation modeling results, and bicycle/pedestrian design and safety considerations.

Network Modeling Center (NMC) Open House

The Network Modeling Center (NMC) at the Center for Transportation Research held an open house on May 1, 2015. The NMC used the event to showcase the tools they've developed to enable regional collaboration and sharing of transportation data. With a theme of "Transforming Regional Transportation through Data," the Open House provided a forum for a conversation about how the NMC's data modeling and storage efforts can benefit public agencies in the region. Hosted at the Texas Advanced Computing Center (TACC) facility on campus, staff also demonstrated how UT Austin's expertise can be leveraged to keep Central Texas on the cutting edge of Big Data applications. Combining the TACC's data storage and analytics capacities—including some of the world's most powerful computing resources—with the NMC's advanced modeling tools creates a win/win scenario for transportation agencies looking to both store and benefit from their Big Data inventories. Noted by NMC Director Dr. Jen Duthie, "May's open house was a significant step in the conversation of leveraging the immense resources at UT to serve the transportation needs of our community."

International Choice Modeling Conference (ICMC)

The 4th International Choice Modelling Conference (ICMC), organized by Resource Systems Group, Inc. (RSG) and the Center for Transportation Research (CTR) at The University of Texas at Austin, was held May 10-13, 2015 in Austin, TX. This was the first ICMC to be held in North America, and brought together leading researchers and practitioners from across different areas of study, with presentations looking both at state of the art methodology as well as innovative real world applications of choice models. An emphasis of the conference was on how to extract value from bog data sources for use in transportation and related fields.

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

Published:

Bernardo, C., R. Paleti, M. Hoklas, and C.R. Bhat (2015), "An Empirical Investigation into the Time-Use and Activity Patterns of Dual-Earner Couples With and Without Young Children," *Transportation Research Part A*, 76, 71-91.

Bhat, C.R. (2015), "A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation," *Transportation*, 42(5), 879-914.

Bhat, C.R. (2015), "A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation," *Transportation Research Part B*, 79, 161-188.

Bhat, C.R. (2015), "A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables," *Transportation Research Part B*, 79, 50-77.

Bhat, C.R., S.K. Dubey, and K. Nagel (2015), "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice," *Transportation Research Part B*, 78, 341-363.

Kamargianni, M., S. Dubey, A. Polydoropoulou, and C. Bhat (2015), "Investigating the Subjective and Objective Factors Influencing Teenagers' School Travel Mode Choice - An Integrated Choice and Latent Variable Model," *Transportation Research Part A*, 78, 473-488.

Jafari, E., M. Gemar, N. Ruiz Juri, N., and J. Duthie (2015) Investigation of Centroid Connector Placement for Advanced Traffic Assignment Models with Added Network Detail. Transportation Research Record: Journal of the Transportation Research Board, 2498, 19-26.

Gopalan, A., C. Caramanis and S. Shakkottai (2015), "Wireless scheduling with partial channel state information: large deviations and optimality." *Queueing Systems*, 80(4), 293-340.

Forthcoming:

Bhat, C.R., M. Castro, and A.R. Pinjari, "Allowing for Complementarity and Rich Substitution Patterns in Multiple Discrete-Continuous Models." *Transportation Research Part B*, forthcoming.

Bhat, C.R., S.K. Dubey, M. Jobair Bin Alam, and W.H. Khushefati, "A New Spatial Multiple Discrete-Continuous Modeling Approach to Land Use Change Analysis." *Journal of Regional Science*, forthcoming.

Shin, J., C.R. Bhat, D. You, V.M. Garikapati, and R.M. Pendyala, "Consumer Preferences and Willingness to Pay for Advanced Vehicle Technology Options and Fuel Types." *Transportation Research Part C*, forthcoming.

Wafa, Z., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "A Latent-Segmentation Based Approach to Investigating the Spatial Transferability of Activity-Travel Models." *Transportation Research Record*, forthcoming.

Boyles, S.D., S. Tang, and A. Unnikrishnan, "Parking Search Equilibrium on a Network." *Transportation Research Part B*, forthcoming.

Khani, A., and S.D. Boyles, "An Exact Algorithm for the Mean–Standard Deviation Shortest Path Problem." *Transportation Research Part B*, forthcoming.

Levin, M., and S.D. Boyles, "Intersection Auctions and Reservation-based Control in Dynamic Traffic Assignment." *Transportation Research Record*, forthcoming.

Levin, M., and S.D. Boyles, "Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice." *Transportation Research Record*, forthcoming.

Chen, Y., H. Xu, C. Caramanis, S. Sanghavi, "Robust Matrix Completion and Corrupted Columns." IEEE *Transactions on Information Theory*, forthcoming.

Under review:

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

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." Submitted to *Transportation Research Part B*.

Fu, X., C.R. Bhat, R.M. Pendyala, S. Vadlamani, and V.M. Garikapati, "Understanding the Multiple Dimensions of Residential Choice." Submitted to *Transportation Letters: The International Journal of Transportation Research*.

Levin, M. W., and S. D. Boyles. "A cell transmission model for dynamic lane reversal with autonomous vehicles." Submitted to *Transportation Research Part C*.

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

Levin, M. W., and S. D. Boyles. "Network-based model for predicting the effect of fuel price on transit ridership and greenhouse gas emissions." Submitted to *Transportation Research Part D*.

Levin, M. W., R. Patel, and S. D. Boyles. "Paradoxes of reservation- based intersection controls in traffic networks." Submitted to *Transportation Research Part A*.

Jafari, E. and S. D. Boyles. "Improved bush-based methods for network contraction." Submitted to *Transportation Research Part B*.

Rusu, C., N. G. Prelcic, and R. W. Heath Jr., "Fast Orthonormal Sparsifying Transforms Based on Householder Reflectors." Submitted to *IEEE Transactions on Signal Processing*.

Choi, J., J. Mo, and R. W. Heath Jr., "Near Maximum-Likelihood Detector and Channel Estimator for Uplink Multiuser Massive MIMO Systems with One-Bit ADCs." Submitted to *IEEE Transactions on Communications*.

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

Pesyna, Jr., K. M., T. Novlan, C. Zhang, R. W. Heath, Jr., and T. E. Humphreys, "Exploiting antenna motion for faster initialization of centimeter-accurate GNSS positioning with low-cost antennas." Submitted to *IEEE Transactions on Aerospace and Electronic Systems*.

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

Presented:

McCoy, T. and J. Duthie, “Dynamic Traffic Modeling for TxDOT.” Presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

Shin, J., "Consumer Preferences and Willingness to Pay for Advanced Vehicle Technology Options and Fuel Types**,**" Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

Dubey, S.K., "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice." Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

Wafa, Z., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "Latent-Segmentation-Based Approach to Investigating Spatial Transferability of Activity-Travel Models." Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

Levin, M., and S.D. Boyles, "Intersection Auctions and Reservation-based Control in Dynamic Traffic Assignment." Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.
Khani, A., E. Jafari, J. Archer, and T. Beduhn, "Impact of Network Accessibility on Schedule-based Transit Assignment." Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

Jafari, E., M. Gemar, N. Ruiz Juri, N., and J. Duthie, "An Investigation of Centroid Connector Placement for Advanced Traffic Assignment Models with Added Network Detail." Poster presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

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Bhat, C.R., "A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables." Presented at the *2015 Joint Statistical Meetings*, Seattle, WA, August 2015.

Boyles, S., L. Gardner, and H. Bar-Gera. "Incorporating Departure Time Choice into High-Occupancy/ Toll (HOT) Algorithm Evaluation." Presented at the *21st International Symposium on Transportation and Traffic Theory (ISTTT21)*, Kobe, Japan, August 2015.

Boyles, S., "Transportation Networks and Optimization." *University Transportation Center-Undergraduate Internship (UTC-UI) Presentations*, UT Austin, August 2015.

Levin, M. W., R. Patel, and S. D. Boyles. "An Assessment of Autonomous Vehicles: Traffic impacts and infrastructure needs." Presented at the *Smart Transport Symposium*, The University of Texas, Austin, TX, August 2015.

Va, V. and R. W. Heath Jr., "Basic Relationship between Channel Coherence Time and Beamwidth in Vehicular Channels." Presented at the *IEEE Vehicular Technology Conference*, Boston, MA, September 2015.

Va, V., X. Zhang, and R. W. Heath Jr., "Beam Switching for Millimeter Wave Communication to Support High Speed Trains." Presented at the *IEEE Vehicular Technology Conference*, Boston, MA, September 2015.

Mitliagkas, I., M. Borokhovich, A. Dimakis, and C. Caramanis, "FrogWild! Fast PageRank Approximations on Graph Engines." Presented at the *41st International Conference on Very Large Data Bases (VLDB)*, Kohala Coast, Hawaii, September 2015.

Duthie, J., "Driving Around in Circles: The Austin Area Traffic & Transportation Dilemma." Presented at the *Austin Branch of the American Association of University Women (AAUW) Monthly Program Meeting*, Austin, TX, September 2015.

Forthcoming Presentations:

Humphreys, T., "Low-Cost Centimeter-Accurate Mobile Positioning," upcoming seminar at the Roadway Safety Institute at University of Minnesota, October 2015.

Choi, J. and R. W. Heath Jr., "Near Maximum-Likelihood Detector with One-Bit ADCs for Multiuser Massive MIMO Systems," to appear in IEEE International Workshop on Computational Advances in Multi-Sensor Adaptive Processing, Cancun, Mexico, December 2015.

Yi X. and C. Caramanis, "Regularized EM Algorithms: A Unified Framework and Statistical Guarantees." To be presented at the *29th Annual Conference on Neural Information Processing Systems (NIPS)*, Montreal, Canada, December 2015.

Presentations Under Review:

Bhat, C.R., "A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation." Submitted for consideration for presentation at the 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 2016.

Bhat, C.R., S. Astroza, and A.C. Bhat, "On Allowing a General Form for Unobserved Heterogeneity in the Multiple Discrete-Continuous Probit Model: Formulation and Application to Tourism Travel." Submitted for consideration for presentation at the 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 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." Submitted for consideration for presentation at the 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 2016.

Bhat, C.R., A.R. Pinjari, and S.K. Dubey "On Accommodating Spatial Interactions in a Generalized Heterogeneous Data Model (GHDM) of Mixed Types of Dependent Variables." Submitted for consideration for presentation at the 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 2016.

Ruiz Juri, N., R.M. James, N. Jiang, J. Duthie, A. Pinjari, and C.R. Bhat, "On the Computation of Skims for Large Scale Implementation of Integrated Activity-based and Dynamic Traffic Assignment Models," Submitted for consideration for presentation at the 95th Annual Meeting of the Transportation Research Board, Washington, DC, January 2016.

Eltayeb, M. E., J. Choi, and R. W. Heath Jr., "On the Security of Millimeter Wave Vehicular Communication Systems using Artificial Noise," submitted to IEEE Vehicular Technology Conference, Nanjing, China, May 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 a lunch event on October 26th as part of Better Streets Week. Better Streets Week is a series of community-facing events in the week leading up to the annual meeting of the National Association of City Transportation Officials (NACTO). Organize presentations regarding connected vehicles during 2015 Texas Wireless Summit to be held October 16, 2015 at UT Austin. The Texas Wireless Summit (TWS) is hosted by the Wireless Networking and Communications Group (WNCG). Organize the 2nd Data Supported Transportation Operations and Planning (D-STOP) Symposium to be held in Spring 2016. Organize a Center for Transportation Research (CTR) Symposium to be held in Spring 2016.

2. PRODUCTS

Publications, conference papers, and presentations:

Journal Publications - Published

Bernardo, C., R. Paleti, M. Hoklas, and C.R. Bhat (2015), "An Empirical Investigation into the Time-Use and Activity Patterns of Dual-Earner Couples With and Without Young Children," *Transportation Research Part A*, 76, 71-91.

Bhat, C.R. (2015), "A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation," *Transportation*, 42(5), 879-914.

Bhat, C.R. (2015), "A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation," *Transportation Research Part B*, 79, 161-188.

Bhat, C.R. (2015), "A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables," *Transportation Research Part B*, 79, 50-77.

Bhat, C.R., S.K. Dubey, and K. Nagel (2015), "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice," *Transportation Research Part B*, 78, 341-363.

Kamargianni, M., S. Dubey, A. Polydoropoulou, and C. Bhat (2015), "Investigating the Subjective and Objective Factors Influencing Teenagers' School Travel Mode Choice - An Integrated Choice and Latent Variable Model," *Transportation Research Part A*, 78, 473-488.

Jafari, E., M. Gemar, N. Ruiz Juri, N., and J. Duthie (2015) Investigation of Centroid Connector Placement for Advanced Traffic Assignment Models with Added Network Detail. Transportation Research Record: Journal of the Transportation Research Board, 2498, 19-26.

Gopalan, A., C. Caramanis and S. Shakkottai (2015), "Wireless scheduling with partial channel state information: large deviations and optimality." *Queueing Systems*, 80(4), 293-340.

Journal Publications - Accepted

Bhat, C.R., M. Castro, and A.R. Pinjari, "Allowing for Complementarity and Rich Substitution Patterns in Multiple Discrete-Continuous Models." *Transportation Research Part B*, forthcoming.

Bhat, C.R., S.K. Dubey, M. Jobair Bin Alam, and W.H. Khushefati, "A New Spatial Multiple Discrete-Continuous Modeling Approach to Land Use Change Analysis." *Journal of Regional Science*, forthcoming.

Shin, J., C.R. Bhat, D. You, V.M. Garikapati, and R.M. Pendyala, "Consumer Preferences and Willingness to Pay for Advanced Vehicle Technology Options and Fuel Types." *Transportation Research Part C*, forthcoming.

Wafa, Z., C.R. Bhat, R.M. Pendyala, and V.M. Garikapati, "A Latent-Segmentation Based Approach to Investigating the Spatial Transferability of Activity-Travel Models." *Transportation Research Record*, forthcoming.

Boyles, S.D., S. Tang, and A. Unnikrishnan, "Parking Search Equilibrium on a Network." *Transportation Research Part B*, forthcoming.

Khani, A., and S.D. Boyles, "An Exact Algorithm for the Mean–Standard Deviation Shortest Path Problem." *Transportation Research Part B*, forthcoming.

Levin, M., and S.D. Boyles, "Intersection Auctions and Reservation-based Control in Dynamic Traffic Assignment." *Transportation Research Record*, forthcoming.

Levin, M., and S.D. Boyles, "Effects of Autonomous Vehicle Ownership on Trip, Mode, and Route Choice." *Transportation Research Record*, forthcoming.

Chen, Y., H. Xu, C. Caramanis, S. Sanghavi, "Robust Matrix Completion and Corrupted Columns." IEEE *Transactions on Information Theory*, forthcoming.

Presentations

McCoy, T. and J. Duthie, “Dynamic Traffic Modeling for TxDOT.” Presented at the *Center for Transportation Research (CTR) Annual Symposium*, Austin, TX, April 2015.

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Websites:
http://dstop.utexas.edu, D-STOP website
http://ctr.utexas.edu/, Center for Transportation Research (CTR)
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

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?

Dallas Police Department, Dallas, TX (in-kind support).
The city of Dallas, TX is working with vendors to evaluate services, technology, and equipment in the area of automatic parking sensor technology. The aim is to modernize parking operations to create "seamless, efficient, customer-friendly, and cost-effective parking operations that are flexible and can easily be modified to fit the needs of various types of parking areas." DSTOP is participating in this effort by assisting the Dallas Police Department with evaluating the quality of data recorded in this pilot project.

Have other collaborators or contacts been involved?

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

We have also discussed DSTOP with several public agencies who are coming 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, and the Texas Dept of Transportation. NCTCOG has initiated a 4-year project to provide matching funds for

D-STOP to examine connected and automated vehicle technology penetration in the DFW area, and transportation planning/operations implications.

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.

The parking equilibrium model developed in D-STOP is a network flow problem with nonlinear flow conservation constraints. This structure is novel across network science. In future years Dr. Boyles will interact with faculty in other areas of network science to determine if other relevant applications exist. The research team also investigated a dynamic pricing problem based on the user equilibrium with recourse framework. We showed that a marginal cost pricing rule in user equilibrium with recourse can minimize expected total system travel time (a state we term "system optimal with recourse.") An interpretation of this is that just as marginal-cost pricing in user equilibrium can address externalities associated with recurring congestion, marginal-cost pricing in user equilibrium with recourse can address externalities associated with nonrecurring congestion.

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.

Our efforts on millimeter wave communication research has great potential for impact on society as more spectrum will likely be made available for millimeter wave (see recent FCC notice of rule making FCC 15-138).

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 CTR Symposium and Secretary Foxx's visit to D-STOP provided a forum for learning and training among approximately 200 attendees, representing a mix of industry, public agencies, and academic participants (see http://ctr.utexas.edu/ctr-symp/ and http://ctr.utexas.edu/2015/05/01/secretary-of-transportation-foxx-visits-ctr/ for more details and photos).

Collaborating with NI and Toyota to implement millimeter wave vehicular communications.

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.