Program Progress Performance Report

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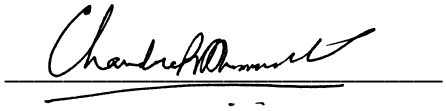
Signature:	

1. ACCOMPLISHMENTS

What are the major goals of the program?

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

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

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

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

What was accomplished under these goals?

Research Program Accomplishments
D-STOP's research activities focus on harnessing innovative technologies and data sources to develop architectures and systems for data collection and analysis. The research will foster economic competitiveness through its focus on gathering and analyzing data to support effective and efficient decision-making. The major research accomplishment during this reporting period was the continued development of the research agenda in coordination with D-STOP faculty and researchers. A total of 18 projects are underway with partial or full funding support from D-STOP.

Ongoing Projects

1. **Cell Phone Data for Travel Forecasting**
   (PI: Jennifer Duthie)
   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.

   Objective:
   - Evaluate the validity of cellular data-based travel demand matrices.
   - Make recommendations for how cellular data can be incorporated into the planning process.

2. **Transit Demand and Routing after Autonomous Vehicle Availability**
   (PI: Stephen Boyles)
   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.

Objectives:

- Model the impact of autonomous vehicle availability on traveler behavior.
- Predict how increasing AV ownership will impact traffic.
- Provide guidance to school on how household AV ownership will affect bus service.

3. **Semi-Autonomous Parking for Enhanced Safety and Efficiency**
   (PI: Sriram Vishwanath)
   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.

   Objectives:

   - Establish a simulation plan for semi-autonomous parking management.
   - Building a 4 robotic vehicle test bed to test algorithms in practice.
   - Determine if there can be increased efficiency in the use of physical space towards parking.

4. **Combining Millimeter-Wave Radar and Communication Paradigms for Automotive Applications: A Signal Processing Approach**
   (Co-PI: Robert Heath and Chandra Bhat)
   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.

   This project will also address the challenges unique to the combined mathematical framework such as beamforming, signal design and mutual interference. Furthermore, the performance of the combined paradigm would be compared with the individual signal frameworks of radar and communication. This will involve a detailed survey, mathematical model development and simulation of both these systems separately. The outcomes of the project are expected to dramatically improve safety for vehicles, bicycles, and pedestrians in all weather conditions and on all roadways.

   Objectives:

   - Develop a mathematical framework for a single signal combined system of V2V and automotive radar, operating at the millimeter-wave frequency. This will dramatically increase the data rates possible between cars and will allow much more information to be exchanged at 100x lower latency than traditional systems.
   - Algorithms would be devised so that the derived information from communication and radar can be shared to enhance the performance of both the paradigms. Our project would bring out and address new challenges in of the areas of common waveform design, antenna arrays/beamforming and trade-off in design parameters.

- 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. Learning Approach to Beam Alignment for mmWave Vehicular Communications (PI: Robert Heath)

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.

Objectives:

- Existing methods for beam alignment at mmWave frequency are largely based on beam sweeping, which is not practical for time-varying environment such as vehicular communications. We leverage vehicle position as side information, which could be obtained, for example, from GPS device. Using a learning approach we avoid idealized assumptions on beam patterns, which will allow the use of low cost hardware.
- Our objective is to develop offline and online learning algorithm for beam alignment. The offline learning will provide an initial mapping as the starting point for operation. Then we will move on to online learning where data are collected and used to refine the table. Learning will incur overhead, however, inadequate learning results in degraded performance.
- The tradeoff between exploration and exploitation will be studied toward the end of this project. Understanding this tradeoff is very crucial to operation of any learning algorithm.

6. Improved Traffic Operations through Real-Time Data Collection and Control (Co-PIs: Stephen Boyles and Sanjay Shakkottai)

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.

Objective:

- Develop novel signal control algorithms, combining knowledge from wireless network routing and transportation network analysis and integrating the “within day” and “day-to-day” time scales.
- Develop novel network pricing algorithms based on a similar perspective, both in HOT lanes and in more general networks.
- Demonstrate the effectiveness of these algorithms in simulation.

7. Models for High Dimensional Mixed Regression (Co-PIs: Constantine Caramanis and Chandra Bhat)

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.).

Objective:

- Develop novel regression-based high dimensional modeling methods for phenomena that represent a mixture of different statistical processes.

8. **Streaming PCA with Many Missing Entries**
   (PI: Constantine Caramanis)
   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.

   Objective:

   - High dimensional streaming PCA with limited memory, able to handle massive amounts of missing data.

9. **Greedy Subspace Clustering**
   (PI: Constantine Caramanis)
   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.

   Objective:

   - How to efficiently do subspace clustering in the large-scale setting.

10. **An Empirical Investigation into the Time-Use and Activity Patterns of Dual-Earner Couples With and Without Young Children**
    (PI: Chandra Bhat)
    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.

Objective:

- Focus on mobility-related social exclusion issues in American society
- Use a multivariate model that recognizes the multiple discrete nature of time-use
- Inform policies to address time poverty & mobility-related social exclusion issues.

11. A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables
(PI: Chandra Bhat)

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.

Objective:

- Formulate a generalized heterogeneous data model for big data applications in transportation planning and operations, using a practical estimation approach

12. A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation
(PI: Chandra Bhat)

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.

Objective:

- Accommodate agent interactions in travel mode choice decisions, while controlling for group formation effects and unobserved heterogeneity

13. High-precision GPS Vehicle Tracking to Improve Safety
(Co-PIs: Jennifer Duthie and Todd Humphreys)

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.

Objective:

- The primary objective of the study is to prove the concept that high-precision GPS traces can be used to identify when drivers are drowsy or distracted, and can help anticipate unsafe situations before they occur.

14. Infrastructure-Informed Travel Sheds
(PI: Jennifer Duthie)

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.

Objective:

- Understand how pedestrians and bicyclists perceive their environment and how this impacts their travel behavior.
- Propose a new method for presenting travel sheds for pedestrians and bicyclists.

15. The Formulation and Estimation of a Spatial Skew-Normal Generalized Ordered-Response Model
(PI: Chandra Bhat)

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.

Objective:

- Formulate a flexible model system for predicting the intensity of land-uses in a region.

16. A Latent Class Multiple Constraint Multiple Discrete-Continuous Extreme Value Model of Time Use and Goods Consumption
(PI: Chandra Bhat)

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.

Objective:

- Advance a new microeconomic framework for time-use of individuals.

17. **A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation**
(PI: Chandra Bhat)
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

Objective:

- Develop an innovative approach to model housing choices, accommodating the search process for dwelling units.

18. **On Accommodating Spatial Interactions in a Generalized Heterogeneous Data Model (GHDM) of Mixed Types of Dependent Variables**
(PI: Chandra Bhat)
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.

Objective:

- Formulate a spatially dependent mixed outcome model and apply it to examine residential location choice, auto ownership, and the count of daily activity episode participations in a suite of different activity purposes.

Research Results Disseminated: Ten papers are forthcoming in refereed journals based on the research projects associated with D-STOP. Several other papers are in the review process. Twenty-four presentations were made at conferences.

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 TxDOT.

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
Rachel Allensworth, supervised by Stephen Boyles
Shubodeep Mukherji, supervised by Todd Humphreys
Ben Wallach, supervised by Jen Duthie

Grad
Swati Agarwal, MS, (supervised by Chandra Bhat)
Sebastian Astroza, PhD, (supervised by Chandra Bhat)
Alice Chu, MS, (supervised by Chandra Bhat)
Subodh Dubey, PhD, (supervised by Chandra Bhat)
Megan Hoklas, MS, (supervised by Chandra Bhat)
Vivek Kumar, MS, (supervised by Chandra Bhat)
Patricia Lavieri, PhD, (supervised by Chandra Bhat)
Zeina Wafa, MS, (supervised by Chandra Bhat)
Tan Wang, MS, (supervised by Chandra Bhat)
Sudesh Agrawal, MS, (supervised by Stephen Boyles)
Ehsan Jafari, PhD, (supervised by Stephen Boyles)
Michael Levin, MS, (supervised by Stephen Boyles)
Tarun Rambha, PhD, (supervised by Stephen Boyles)
Shoupeng Tang, PhD, (supervised by Stephen Boyles)
Tyler Beduhn, MS, (supervised by Jennifer Duthie)
Rachel James, PhD, (supervised by Jennifer Duthie)
Ankita Chaudhary, MS, (supervised by Jennifer Duthie)
Xinyang Yi, PhD, (supervised by Constantine Caramanis)
Ioannis Mitliagkas, PhD, (supervised by Constantine Caramanis)
Dohyung Park, PhD, (supervised by Constantine Caramanis)
Preeti Kumari, MS, (supervised by Robert Heath)
Vutha Va, PhD, (supervised by Robert Heath)
Andrew Kerns, PhD, (supervised by Todd Humphreys)
Ken Pesyna, PhD, (supervised by Todd Humphreys)
Tzu-Ling Kan, MS, (supervised by Sanjay Shakkottai)
Yan Gao, MS (supervised by Sriram Vishwanath)

The D-STOP Center selected MS student Michael Levin (supervised by Dr. Steve Boyles) as its 2014 Outstanding Student of the Year. Michael was recognized at an annual awards banquet in January 2015 in Washington DC before the TRB Annual Meeting.

Education and Workforce Development Results Disseminated:
Outreach Activity: Dr. Sanjay Shakkottai presented a lecture in December 2014 on 'Mobile Computing' to local Austin middle school students through Breakthrough Austin. Breakthrough Austin is a community program that provides a path through college, beginning in middle school, for low-income students who will become first-generation college graduates.

Dr. Sanjay Shakkottai was also a distinguished lecturer at the eleventh annual Edison Lecture Series on February 17-19, 2015. The theme for 2015 was ‘Big Data'. The Edison Lecture Series, a Science, Technology, Engineering and Mathematics (STEM) Education Coalition program, invites middle and high school students and their teachers to a three-day workshop on the UT-Austin campus.

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:
Constitute Business Advisory Council (BAC) and hold BAC meeting. Recruit and introduce a fresh batch of graduate students to D-STOP. The University Transportation Center-Undergraduate Internship (UTC-UI) program will be held for a second year in the summer of 2015, and organization is underway. Each intern will participate in a research project related to the D-STOP center, and a weekly seminar will be held.

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:
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. The symposium disseminated cutting edge research of relevance to work toward ways to reduce the incubation time from research to implementation. Also, the opportunity for our researchers to network and interact with industry and public government leaders contributed to research activities of the D-STOP Center, while serving to foster additional technology transfer pursuits of D-STOP. 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.

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

Forthcoming:

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

Bhat, C.R., " A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation." *Transportation*, forthcoming.

Bhat, C.R., S.K. Dubey, and K. Nagel, "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice." *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.

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

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." *Transportation Research Record*, 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.

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.

Under review:

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

Bhat, C.R., "A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation." Submitted to *Transportation Research Part B*.

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

Kamargianni, M., S.K. Dubey, A. Polydoropoulou, and C.R. Bhat, "Investigating the Subjective and Objective Factors Influencing Teenagers' School Travel Mode Choice - An Integrated Choice and Latent Variable Model." Submitted to *Transportation Research Part A*.

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." Submitted to *Transportation Research Part C*.

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

Presented:

Bhat, C.R., "Accommodating the Multidimensional Nature of Integrated Models: Emerging Methods and Challenges in Capturing Cause-Effect Relationship." Workshop 117**:** Integrated Land-use, Travel Demand, Air Quality, and Exposure Modeling: the Future of Regional Transportation Planning?, *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., "A New Generalized Heterogeneous Data Model (GHDM) with Applications to Integrated Land-use and Transport Modeling." Workshop 156: Emerging Data Technology and Analytic Frontiers in Integrated Land-Use and Transport Modeling, *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., "A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., and S. Dubey "A New Spatial (Social) Interaction Discrete Choice Model Accommodating Self-Selection in Group Formation." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., S.K. Dubey, and K. Nagel, "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., X. Fu, and S.K. Dubey, "A Simulation Evaluation of the Maximum Approximate Composite Marginal Likelihood (MACML) Estimator for the Generalized Heterogeneous Data Model (GHMD)." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Boyles, S.D., S. Tang, and A. Unnikrishnan, "Parking Search Equilibrium on a Network." Presented at *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 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." Presented at *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

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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 Board (TRB) Annual Meeting*, Washington, DC, January 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." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., "New High-Dimensional Data Analysis Techniques for Urban Planning." *Invited Seminar*, Central Road Research Institute (CRRI), Delhi, India, January 2015.

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Bhat, C.R., "A Comprehensive Dwelling Unit Choice Model Accommodating Psychological Constructs Within A Search Strategy for Consideration Set Formation." *Invited Seminar*, Department of Civil and Environmental Engineering, MIT, Cambridge, MA, February 2015.

Bhat, C.R., "A New Generalized Mixed Data Model with Applications to Transport Analysis." *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, March 2015.

Boyles, S.D., "Automated Traffic Control Paradigms: Thinking Beyond Signals." *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, March 2015.

Heath Jr., R.W., "Vehicular MmWave Communication and Joint Communication-Radars: Opportunities and Challenges." *Data Supported Transportation Operations and Planning (D-STOP) Symposium*, Austin, TX, March 2015.

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Duthie, J., "Safety Research at the Data-Supported Transportation Operations and Planning (D-STOP) UTC." *A Summit of University Transportation Centers for Safety*, Pittsburgh, PA, March 2015.

Forthcoming Presentation:

Boyles, S., L. Gardner, and H. Bar-Gera. "Incorporating departure time choice into high-occupancy/toll (HOT) algorithm evaluation." To be presented at the 21st International Symposium on Transportation and Traffic Theory (ISTTT), Kobe, Japan, July 2015.

Presentations Under Review:

Kumari, P., N. Gonzalez-Prelcic, and R. W. Heath Jr., "Investigating the IEEE 802.11ad Standard for Millimeter Wave Automotive Radar." Submitted to the Proceedings of the IEEE Vehicular Technology Conference, Boston, USA Sept. 6-9, 2015.

Va, V. and R. W. Heath Jr., "Basic Relationship between Channel Coherence Time and Beamwidth in Vehicular Channels." Submitted to the Proceedings of the IEEE Vehicular Technology Conference, Boston, USA Sept. 6-9, 2015.

Va, V., X. Zhang, and R. W. Heath Jr., "Millimeter Wave Communication to Support High Speed Trains." Submitted to the Proceedings of the IEEE Vehicular Technology Conference, Boston, USA Sept. 6-9, 2015.

Plans for Next Reporting Period to Accomplish Technology Transfer Goal: Continue to support researchers as they present their research results through peer-reviewed publications and professional presentations. Organize a Center for Transportation Research (CTR) Symposium to be held April 8, 2015. Host Secretary Foxx on his visit to D-STOP on April 24, 2015. Organize an open house to showcase D-STOP related research projects and results on May 1, 2015. Organize an International Choice Modeling Conference (ICMC) in Austin, to be held May 10-13, 2015.

2. PRODUCTS

Publications, conference papers, and presentations:

Journal Publications - Accepted

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

Bhat, C.R., " A New Spatial (Social) Interaction Discrete Choice Model Accommodating for Unobserved Effects due to Endogenous Network Formation." *Transportation*, forthcoming.

Bhat, C.R., S.K. Dubey, and K. Nagel, "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice." *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.

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

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." *Transportation Research Record*, 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.

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.

Conference Presentations

Bhat, C.R., "Accommodating the Multidimensional Nature of Integrated Models: Emerging Methods and Challenges in Capturing Cause-Effect Relationship." Workshop 117**:** Integrated Land-use, Travel Demand, Air Quality, and Exposure Modeling: the Future of Regional Transportation Planning?, *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., "A New Generalized Heterogeneous Data Model (GHDM) with Applications to Integrated Land-use and Transport Modeling." Workshop 156: Emerging Data Technology and Analytic Frontiers in Integrated Land-Use and Transport Modeling, *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., "A New Generalized Heterogeneous Data Model (GHDM) to Jointly Model Mixed Types of Dependent Variables." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., and S. Dubey "A New Spatial (Social) Interaction Discrete Choice Model Accommodating Self-Selection in Group Formation." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., S.K. Dubey, and K. Nagel, "Introducing Non-Normality of Latent Psychological Constructs in Choice Modeling with an Application to Bicyclist Route Choice." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Bhat, C.R., X. Fu, and S.K. Dubey, "A Simulation Evaluation of the Maximum Approximate Composite Marginal Likelihood (MACML) Estimator for the Generalized Heterogeneous Data Model (GHMD)." *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

Boyles, S.D., S. Tang, and A. Unnikrishnan, "Parking Search Equilibrium on a Network." Presented at *Transportation Research Board (TRB) Annual Meeting*, Washington, DC, January 2015.

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Duthie, J., "Safety Research at the Data-Supported Transportation Operations and Planning (D-STOP) UTC." *A Summit of University Transportation Centers for Safety*, Pittsburgh, PA, March 2015.

Websites:
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

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, and the City of Austin, Texas.

4. IMPACT

Impact on the development of the principal disciplines of the program:
Two forthcoming papers by DSTOP-supported research presented the first models which can be used to integrate parking management into the transportation planning process. In those papers, considerable efforts have been made to understand the behavior of such systems, as a fundamental advance in transportation science.

Five forthcoming papers based on D-STOP research develop methods to deal with latent variables in land use-transportation modeling, joint analysis of mixed types of variables, and time-use/transferability analysis.

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: Nothing to report for this period.

Impact on technology transfer:
The D-STOP Symposium provided a forum for learning and training among approximately 90 attendees, representing a mix of industry, public agencies, and academic participants (see http://ctr.utexas.edu/research/d-stop/education/annual-symposium/ for more details and videos).

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

5. CHANGES/PROBLEMS

Nothing to report.

Data Supported Transportation Operations and Planning (D-STOP) Symposium

"Pathways to a Connected / Autonomous Transportation World"

Monday, March 2, 2015
AT&T Executive Education and Conference Center at The University of Texas at Austin;
1900 University Avenue, Austin TX 78705; http://www.meetattexas.com/

Symposium Agenda

7:00 AM - 8:00 AM: Breakfast at the Symposium Venue

8:00 AM - 8:15 AM: **Welcome and Overview of the Symposium Structure** (Chandra Bhat)

8:15 AM - 9:15 AM: **Setting the Stage: Perspectives from Academia and Public Agencies**
(Moderator: Chandra Bhat)

- ***A Perspective of a Connected and Autonomous Transportation System***
  C. Michael Walton, Ernest H. Cockrell Centennial Chair in Engineering, Dept of Civil, Architectural and Environmental Engineering, UT Austin
- ***Setting the Stage: a Texas Perspective***
  John Barton, Deputy Executive Director, Texas Department of Transportation

9:15 AM - 9:30 AM: Break

9:30 AM - 10:45 AM: **"High Dimensional Heterogeneous Data Analysis in a Big Data World"**
(Moderator: Constantine Caramanis)

Description: In the Big-Data view of the world, everything is a sensor — legacy roadway systems, new (and perhaps limited deployments), and sensors in personal devices, from smart phones and GPS systems to smart cars themselves. To leverage these synergistically for not only sensing, but also prediction, requires the ability to deal with data that may be highly noisy, heterogeneous, and high-dimensional. Our panelists are drawn from experts in modeling human behavior, in prediction and planning, and data mining and predictive modeling.

- ***A New Generalized Mixed Data Model with Applications to Transport Analysis***
  Chandra Bhat, Director of D-STOP and CTR, and the Adnan Abou-Ayyash Centennial Professor in Transportation Engineering at UT Austin
- ***Approaches to Mining Large-Scale Heterogeneous Data: Old and New***
  Joydeep Ghosh, Schlumberger Centennial Chair Professor, Dept. of Elec. and Comp. Engr, UT Austin
- ***Using Microsimulation to Recover Heterogeneity from Aggregated Data***
  Doug Fearing, Assistant Professor, McCombs School of Business, UT Austin
- ***Enriching IoT Analytics with Multi-tiered Video Sensing***
  Xiaoqing Zhu, Technical Leader, Cisco Systems

10:45 AM - 11:00 AM: Break

11:00 AM - 12:15 PM: **"Communications and Radar-Supported Transportation"**
(Moderator: Joydeep Ghosh)

Description: This session will discuss multimodal and multidisciplinary efforts to integrate cutting-edge developments in communications, radar, and sensing in transportation systems, especially for roadway safety applications. Technology experts will review key features of relevant technologies related to dedicated short range communication, automotive radar, and other sensing modalities. The session will conclude with a panel discussion that focuses on the potential impact of technology advancements on the next generation of connected vehicles.

- ***Automotive RADAR Adoption—An Overview***
  Ram Mirwani, Director of Global Strategic Accounts, AWR, National Instruments
- ***5.9 GHz DSRC Radio Communications in the Emerging Connected/Automated Vehicle World***
  Randal Roebuck, Advanced Technology Specialist, 3M Traffic Safety Systems
- ***Vehicular MmWave Communication and Joint Communication-Radars: Opportunities and Challenges***
  Robert Heath, Cullen Trust Endowed Professor, Department of Electrical and Computer Engineering, UT Austin

12:15 pm - 1:30 pm: Networking Lunch

1:30 pm - 2:45 pm: **"GPS-based Vehicle Trajectories and Applications"**
(Moderators: Jennifer Duthie and Todd Humphreys)

Description: Location is at the heart of intelligent transportation, for both safety and improved efficiency. This panel will explore the uses and benefits of vehicle tracking at both coarse- and fine-grained resolution. Raw location data can be combined with maps and traffic models to deliver accurate traffic measurement and powerful traffic prediction. The panel will discuss the mechanics of how the location data are obtained and the reasons behind the various location errors that can corrupt the data. Applicability to a broad range of vehicles will be discussed, from vehicle fleets to personal automobiles to bicycles.

- ***Vehicle Tracking with Fine-Grained GPS and Implications for Safety***
  Todd Humphreys, Assistant Professor, Department of Aerospace Engineering and Engineering Mechanics, UT Austin
- ***Metropia App and Implications for Travel Demand Management***
  Yi-Chang Chiu, Associate Professor, Department of Civil Engineering and Engineering Mechanics, University of Arizona; Founder, Metropia
- ***An App for Bicycle Travel through Intersections***
  Tom Fowler, Vice President, Kimley-Horn and Associates, Inc.
- ***Matching GTFS Transit Route Data to a Roadway Network for Travel Modeling***
  Ken Perrine, Research Associate, Network Modeling Center, UT Austin

2:45 pm - 3:00 pm: Break

3:00 pm - 4:15 pm: **"Improved Traffic Operations in a Connected/Automated World"**
(Moderators: Stephen Boyles and Sanjay Shakkottai)

Description: New communication technologies are revolutionizing the way transportation systems can be managed. This session highlights several of these ways, ranging from adaptive signal control already used in practice to future possibilities that can be realized when most vehicles on the road are autonomous. A brief discussion by the panelists will follow their presentations.

- ***Automated Traffic Control Paradigms: Thinking Beyond Signals***
  Stephen Boyles, Assistant Professor, Department of Civil, Architectural and Environmental Engineering, UT Austin
- ***MetroRapid Transit Signal Priority-Using Technology to Improve Service Quality***
  Todd Hemingson, VP Strategic Planning & Development, Capital Metro
- ***Technology Roadmap for Vehicle-centric Wireless Communications***
  Thomas Novlan, Staff Research Engineer, Samsung Research America

4:15 pm - 4:45 pm: General discussions and wrap-up