

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Robert W. Heath Jr.

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	Spatial Correlation Estimation of Millimeter Vehicular Communication Channels Using Out-of-Band Information
Start Date	5/1/2017
Expected End Date	5/31/2018

Why is this a problem or opportunity?

Wireless channels in vehicular communications systems rapidly vary due to the fast changes of their topology. Obtaining reliable instantaneous information about the propagation channel is invariably important in wireless communications. It is more challenging in vehicular communication systems especially at millimeter wave (mmWave) bands since the problem is further exacerbated by the hardware constraints required for mmWave systems. For example, a small number of RF chains and low-resolution ADCs enforce to limit to the number of measurements for and the direct access to the channels between transceivers.

Compared to the instantaneous channel information, the second order statistics (or the spatial correlation) of the channels vary slowly so it is relatively not hard to obtain them in general. In the case of mmWave systems, however, even acquiring the second order statics is still difficult because of the lack of direct access to the channel and possibly many transmit/receive antennas with hybrid beamforming architectures - inducing high training overhead. Therefore, to overcome the problem, we aim at developing a framework to leverage the second order statistics of out-of-band channels and to estimate mmWave channel correlations by using them. Specifically, algorithms will be developed to fetch out-of-band information from sub-6 GHz channels use this information for mmWave channel correlation estimation.

What are you going to do?

- Design algorithms to fetch the desired information from the sub-6 GHz channel.
- Design a framework to leverage the sub-6 GHz information for the mmWave correlation estimation.
- Reduce the training overhead of mmWave channel correlation estimation.

How will you involve graduate students?

Graduate students will be directly involved in this project. They will develop algorithms to fetch sub-6 GHz channel information and develop a framework to leverage this information for

mmWave correlation estimation. The students will also evaluate the proposed algorithms with simulations and/or actual measurements.

How can your results be used?

The result developed in this project will guide designing mmWave channel estimation methods using out-of-band information for vehicular communication systems and complement the on-going vehicular communication projects funded by TxDOT.

How will you tell or show your results to others?

The results will be published in the form of a journal article, conference paper, and final technical report.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Robert W. Heath Jr.

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	Joint Millimeter-Wave Communication and Radar for Automotive Applications
Start Date	5/1/2017
Expected End Date	5/31/2018

Why is this a problem or opportunity?

Vehicular radar and communication are the two primary means of using radio frequency (RF) signals in transportation systems. Automotive radars provide high-resolution sensing using proprietary waveforms in millimeter wave (mmWave) bands and vehicular communications allow vehicles to exchange safety messages or raw sensor data. Both the techniques can be used for applications such as forward collision warning, cooperative adaptive cruise control, and pre-crash applications.

The project aims at developing a mmWave vehicular joint system that exploits the same waveform for both communication and radar operations, thus allowing hardware reuse. The use of a standard mmWave waveform, which provides access to a large bandwidth, will lead to significant advantages in terms of higher data rates for communication and better accuracy/resolution for radar operation compared with approaches based on sub-6 GHz frequencies. Our initial work was to propose the idea of using IEEE 802.11ad for a joint vehicular communication and radar system. This allows us to exploit the same spectrum and to leverage shared hardware based on the mmWave consumer WLAN standard. The approach is reasonable because the most prevalent vehicular communication standard, dedicated short-range communications (DSRC), is based on the WLAN standard. In this project, we propose to refine previously developed algorithms and develop a further framework and associated algorithm to better achieve vehicular radar and communication objectives. These algorithms shall be used for designing modified IEEE 802.11ad and associated processing techniques (e.g., by exploiting sparsity) that permit both radar and communication functionalities in a multi-target scenario. The results will allow insights about how to design an optimal joint waveform for different vehicular scenarios to meet the continuously growing performance requirements of a more advanced assisted driving and future autonomous driving.

What are you going to do?

- Propose signal processing algorithms to further enhance joint millimeter wave radar and communication systems.

- Design modified IEEE 802.11ad waveforms and incorporate multi-target radar models and refined algorithms (e.g., exploiting sparsity) to better adapt to different vehicular environments.

How will you involve graduate students?

They will develop advanced frameworks and algorithms for enhanced joint communication and radar system and evaluate the proposed frameworks with simulations and/or actual measurements.

How can your results be used?

The result developed in this project will guide designing mmWave joint communication and radar systems and complement the on-going vehicular communication projects funded by TxDOT.

How will you tell or show your results to others?

The results will be published in the form of a journal article, conference paper, and final technical report.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Todd Humphreys

Name(s) of Proposed Collaborator(s):

Gaurav Bansal (Toyota ITC); Robert Heath

Project Info

Project Title	Cooperative Mapping for Automated Vehicles
Start Date	1/1/2017
Expected End Date	9/29/2017

Why is this a problem or opportunity?

Localization is essential for automated vehicles, even for simple tasks such as lane- keeping. Some automated vehicle systems use their sensors to perceive their surroundings on-the-fly, such as the early variants of the Tesla Autopilot, while others such as the Waymo car navigate within a prior map. The latter approach is beneficial in that it helps the system to expect the expected, that is, it relieves the system of perceiving static features. However, making and updating such accurate prior maps using a specialized vehicle fleet is expensive and cumbersome. A key enabler for large-scale up-to-date maps will be enlisting the help of the very vehicles who need the map—consumer vehicles—to build and update the map. This project explores the possibility of using multiple vehicles equipped with the kinds of sensors that are (or will be) common on cars (optical cameras, radar, IMU, and GNSS) to perform cooperative SLAM for improving and updating a point-feature map 3D map of the environment.

What are you going to do?

Phase 1.1 (Feb. 1, 2017 – Mar. 31, 2017)

Objectives — The following tasks will be performed as Phase 1.1 of this project:

(1) Literature Review:

Identify and compare different SLAM techniques appropriate for cooperative mapping using the given sensor data.

(2) Data Collation and Verification:

Capture and merge data from a sensor suite with stereo optical cameras, automotive radar, consumer-grade IMU, and carrier-phase differential GNSS (CDGNSS) receiver. The CDGNSS receiver will be used to generate the ground truth trajectory in this phase of the project. The outcomes of this objective will be

(2.1) Time-synchronized storage and pre-processing of data including checks for missing data frames, outliers, etc.

(2.2) Knowledge on best practices in data collection and verification using a low-cost sensor suite for mapping and localization.

(2.3) Development of efficient software for minimal overhead assimilation of voluminous sensor data.

(2.4) First-cut calibration of the stereo cameras' extrinsic (e.g., mounting, inter-camera spacing) and intrinsic (e.g., lens distortion) parameters.

(3) Preliminary Cooperative SLAM Results:

The stereo camera data collected using the aforementioned sensor suite will be processed using existing SLAM algorithms to create a 3-D map of a route in a light-urban setting. The output from different SLAM techniques will be compared with CDGNSS-based ground truth, yielding results on and insight into cooperative SLAM.

Deliverables -- The team will deliver a technical memorandum summarizing the results from Phase 1.1. In addition, the data collected using the developed sensor suite, along with the required software, will be transferred to Toyota ITC, if requested. Suitable tools for visualization of 3D maps will be included.

Phase 1.2 (Apr. 1, 2017 – Sept. 29, 2017)

Objectives — The following tasks will be performed as Phase 1.2 of this project:

(1) Radar Maps:

The utility of radar traces obtained from an automotive radar unit will be explored for the purpose of mapping. The radar maps will be fused with maps generated using the stereo camera setup.

(2) Cooperative Mapping:

Technique for using raw sensor data from two vehicles (or two separate runs of the same vehicle) to generate a cooperative map will be developed. This fusion of maps will only use the meter-accurate variant of GNSS, and will be based on the bundle-adjustment technique. The extension from individual-vehicle-SLAM to cooperative SLAM is challenging because the bundle-adjustment algorithm complexity scales exponentially in the number of keyframes to be processed. This precludes the possibility of using raw keyframes from an arbitrarily large time window or from a large number of vehicles simultaneously. One candidate solution is to frequently summarize the data in the form of a correlation matrix, as is commonly done in filtering techniques. However, such summarization destroys the sparse nature of the matrices involved in the bundle-adjustment algorithm, again leading to inefficient implementation. This is still an open problem and constitutes the primary theoretical challenge of the project.

Deliverables: The team will deliver a technical memorandum summarizing the theory behind the developed cooperative mapping technique and preliminary results from the resulting on-vehicle implementation.

How will you involve graduate students?

Three graduate students will work on this project. Lakshay Narula will focus on visual SLAM, Michael Wooten will work on mapping using radar, and Matthew Murrian will be in charge of optimal GNSS fusion.

How can your results be used?

These results can be used immediately by automotive OEMs for crowd-sourced mapping and localization. As such, this is a wide area of research, and will lead to extensions with Toyota and, possibly, with other automakers.

How will you tell or show your results to others?

Appropriate visualization software and packages will be developed for visual evaluation of algorithms. Suitable charts will be generated for statistical evaluation. These results will be presented at conferences such as the IEEE Intelligent Vehicles Symposium, journals such as IJRR, and internal and public presentations.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Todd Humphreys

Name(s) of Proposed Collaborator(s):

Robert Heath

Project Info

Project Title	ADAS Enhanced by 5G Connectivity
Start Date	9/30/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

Advanced driver assistance systems (ADAS) are a key technology for improved traffic safety. Long before fully automated vehicles arrive in significant numbers, ADAS will see high penetration and substantially reduce accident rates. Toyota and Honda have both committed to focusing on “hands on the wheel, eyes on the road” ADAS long before (perhaps up to a decade) introducing higher levels of automation to consumers. This is a philosophy that resonates with the PI and co-investigator of this project.

Connectivity between vehicles, and between vehicles and infrastructure, makes ADAS more effective by enabling vehicles to “see” around corners and through other vehicles. But connectivity via DSRC, the 802.11-based standard that will likely be mandated by 2020, can become congested when a large number of vehicles, cyclists, and pedestrians congregate near intersections in urban areas. Moreover, DSRC does not offer the bandwidth for sharing of raw, or lightly-processed, sensor data between vehicles or from infrastructure to vehicles. In fact, in all likelihood, DSRC message traffic will be limited to the basic safety message, a low-rate, low-latency message that communicates a vehicle’s or cyclist’s or pedestrian’s current position and velocity to others in the vicinity. And even this message will become unreliable if too many DSRC transmitters find themselves fighting for slots in which to transmit, such as will occur in urban areas with heavy foot and vehicular traffic.

This project aims to study how emerging 5G technology can be used to “supercharge” ADAS by releasing it from the limitations of DSRC. How can ADAS benefit from the sub-10-ms latency, the 100 Mbps per-user download data rate, and the high connection density that 5G promises?

What are you going to do?

Partnering with an automotive OEM (either Toyota or Honda), we intend to study the following:

1. How can infrastructure-mounted cameras, and possibly infrastructure-mounted radar units, be used to provide better situational awareness to in-vehicle ADAS? Is it practical to send raw images or radar returns from roadside sensors to vehicle ADAS via 5G?
2. Can the benefit of infrastructure-aided ADAS be quantified in terms of a reduction in risk (as defined by a cost-probability product)?
3. How does vehicle positioning improve if GNSS corrections are sent with low latency over 5G, as opposed to no corrections with the standard positioning service?
4. Can UAVs play a role in helping a vehicle piece together a fuller picture of its surroundings? Might individual vehicles be equipped with their own “eyes in the sky” UAV, to be deployed as necessary to fill in gaps in the vehicle’s instantaneous area map (including the location and movement of pedestrians, cyclists, etc.)?

How will you involve graduate students?

At least three graduate students will work on this project. Lakshay Narula will focus on vision sensors and map construction, Michael Wooten will focus on radar sensors, and Matthew Murrian will work on fusion algorithms.

How can your results be used?

These results can be used immediately by automotive OEMs for improved ADAS—even before 5G begins to be realized. Existing 4G LTE will be adequate for some infrastructure aiding of ADAS. As such, this is a wide area of research, and will lead to extensions with Toyota, Honda, and, possibly, with other automakers.

How will you tell or show your results to others?

Appropriate visualization software and packages will be developed for visual evaluation of algorithms. Suitable charts will be generated for statistical evaluation. These results will be presented at conferences such as the IEEE Intelligent Vehicles Symposium, journals such as IJRR, and internal and public presentations.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Steve Boyles

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	Improved Models for Managed Lane Operations
Start Date	9/1/2017
Expected End Date	8/31/2018

Why is this a problem or opportunity?

Managed lanes (ML) are increasingly being considered as a tool to mitigate congestion on highways with limited areas for capacity expansion. Managed lanes are dynamically priced based on the congestion level, and can be set either with the objective of maximum utilization (e.g., a public operator) or profit maximization (e.g., a private operator). Optimization models for determining these pricing policies make restrictive assumptions about the layout of these corridors (often a single entrance and exit) or knowledge of traveler characteristics on behalf of the modeler (e.g., distribution of willingness to pay). Developing new models to address these issues would allow for better utilization of these facilities.

What are you going to do?

In this project, we will study dynamic pricing models for managed lanes. We will focus on two aspects of dynamic pricing: (a) utilizing real time traffic measurements to inform parameters of the pricing model, and (b) developing a optimal pricing formulation for managed lanes with multiple entrances and exits.

(a) We will first develop a non-linear estimation model to determine the parameters of the value of time (VOT) distribution using real time loop detector measurements. The observability of the collected measurements to estimate the parameters of the model is a primary factor which will affect the ability of the non-linear estimation to work in real time.

(b) We will investigate a dynamic programming formulation to solve distance based optimal tolling for HOT lanes with multiple entrances and exits under deterministic demand conditions. We will consider two optimization objectives are considered: maximizing the generated revenue, and minimizing the experienced total system travel time (TSTT). We propose a spatial queue model for capturing the traffic dynamics, and a multinomial logit model for simulating lane choice at each diverge node.

How will you involve graduate students?

A major portion of the funds for the proposed project will be allocated for graduate student involvement. Venktesh Pandey, a Ph.D. student with experience in traffic flow and strong knowledge of active traffic management strategies, will be heavily involved in the methodological development needed for this research.

How can your results be used?

This project directly addresses a practical problem associated with operating managed lanes and calibrating simulation models. The results may lead to future improvements in static and dynamic traffic assignment software and lay the foundation for further research sponsored by an agency such as the National Science Foundation.

How will you tell or show your results to others?

Technology transfer will be accomplished through interaction with public agencies involved in transportation planning and who use traffic assignment as a component of their models (such as CAMPO or NCTCOG). Throughout the research process, the research team will maintain close communication with these agencies to guide the modeling process. Dissemination will also be achieved through submission of papers for publication in leading transportation journals (such as Transportation Science or Transportation Research Part B) and presentation of the approach at national and international conferences (such as the annual meetings of the Transportation Research Board and Institute for Operations Research and Management Sciences).

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Chandra Bhat

Name(s) of Proposed Collaborator(s):

Natalia Ruiz, James Kuhr

Project Info

Project Title	Capturing the Impacts of Ride-sourcing and HOVs
Start Date	9/1/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

One new paradigm of particular interest is the possibility of a mobility shift to heavy reliance on ride-sourcing services provided by transportation network companies (TNCs). Ride-sourcing services allow users to contact and utilize third parties for rides. After just over seven years of exposure to TNCs in the United States, there is market evidence of general widespread acceptance for ride-sourcing as an innovative and valuable augmentation to transportation systems.

Still, while the supply market may be showing overt signs of embracing the ride-sourcing paradigm, consumer attitudes towards adoption remain uncertain. Moreover, the potential system-wide impacts of a drastic shift to autonomous ride-sourcing require a careful examination. Unintended outcomes, such as a significant increase in vehicles-miles-traveled, may lead to additional congestion, which can in turn affect choices such as residential location and trip making patterns. In this context, the use of behavioral models is critical to comprehensively assess the evolution of ride-sharing and HOVs.

What are you going to do?

Conduct a survey in Texas – either in Austin or another large metropolitan area. This could be done via a new survey or leveraging existing survey instruments and technologies. We plan to conduct at least two waves of a panel survey (longitudinal data collection), a year apart to help analyze the change in attitudes and preferences towards adoption of ride-sourcing and autonomous vehicles over time. The use of web-based/mobile technologies to facilitate the surveying process and the corresponding data analyses will be considered. The latter may also facilitate continuous/repeated surveying, and potentially the transferability of survey instruments. The results of this survey will be cataloged in a report and be used to inform the future construction of behavioral models.

How will you involve graduate students?

Graduate students will do a significant portion of the work, and assist in survey development and dissemination, literature review and compilation of the results

How can your results be used?

These results will be used to help influence the construction of new behavioral models that consider ridesourcing options. They will be complemented with significant funding from private sector sources and contribute material research to the state of the art in long range transportation planning.

How will you tell or show your results to others?

Our work will be disseminated through a comprehensive D-STOP report, through at least one paper for TRB and workshops at the TRB annual meeting. Further, it will be publicized on the CTR website and through various state and local level conferences when available.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

James Kuhr

Name(s) of Proposed Collaborator(s):

Chandra Bhat, Natalia Ruiz

Project Info

Project Title	V2I Managed Lanes Test Bed
Start Date	9/1/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

Vehicle-to-Everything (V2X) technology connects vehicles, infrastructure, and any other communicating devices. By sending and receiving short communications, known as Basic Safety Messages (BSMs), vehicles will receive key information about their surroundings that can be relayed to their drivers to aid safe operations. The potential for safety applications under a mature V2X system is tremendous: through use of a mature system, NHTSA studies indicate that 81 percent of all unimpaired crashes could be avoided.

Research is critical to better understand how communication technologies may support or limit the potential impacts of connected vehicles. The project will investigate V2I communication technology to be installed along connected roadways, including DSRC, LTE and potential 5G technologies, and investigate V2I privacy and security threats.

What are you going to do?

- Perform a comprehensive investigation into V2I technology and road side units, leveraging in house knowledge, experience and test models of the Wireless Networking Communications Group
- Perform an in-depth analysis of current V2I installations underway
- Catalog and report on potential installation technologies, their estimated Total Installed Costs and their respective capabilities.
- Perform a literature review of existing studies involving behavior acceptance and preference for connected vehicles.
- Write a report detailing the findings.

How will you involve graduate students?

Graduate students will do a significant portion of the work. They will assist in literature review and investigation into existing technologies, and writing the final report.

How can your results be used?

These results will be used to help define V2X installations for the State of Texas and the wider United State. They will be complemented with significant funding from private sector sources, the Texas Department of Transportation and contribute material research to intelligent transportation systems planning and installation.

How will you tell or show your results to others?

Our work will be disseminated through a comprehensive D-STOP report, through at least one paper for TRB and workshops at the TRB annual meeting. Further, it will be publicized on the CTR website and through various state and local level conferences when available. Finally, it will be used to support further funding applications for infrastructure related grants.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Natalia Ruiz

Name(s) of Proposed Collaborator(s):

Chandra Bhat, James Kuhr

Project Info

Project Title	Transition Period from Today to Fully Autonomous
Start Date	9/1/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

Thanks to innovations from Silicon Valley, what was once thought to be a timeline that would introduce autonomous vehicles by 2035 has turned into a race to produce autonomous vehicles as fast as possible; now, the horizon for commercially available autonomous vehicles appears to be at the beginning of the next decade. However, CAVs will coexist with regular vehicles for several decades, and understanding traffic patterns during the transition period is critical to support planning and operations decisions. While behavioral modeling tools may be used to conduct such an assessment, it is also important to consider that models may require substantial changes in order to capture the impact of CAVs on traffic flow.

This research will work to understand the challenges of capturing the impacts of CAVs for different traffic models. Propose adequate methodologies to incorporate CAVs into the traffic models used in this project and estimate model parameters to reflect the impact of CAVs in the selected traffic model.

What are you going to do?

- Researchers will investigate different approaches to modeling CAVs in typical traffic models and identify challenges and limitations of existing modeling tools.
- Select a modeling approach appropriate for the scope of this project and identify benefits and potential limitations.
- Identify required adjustments and write a report on what is needed to change the model to consider autonomous and connected vehicle traffic.

How will you involve graduate students?

Graduate students will do a significant portion of the work. They will assist in literature review and investigation into typical traffic models used in modeling currently. They will investigate methods to change these models to emulate the mix of autonomous and connected vehicles, and write the report detailing their findings.

How can your results be used?

These results will be used to help define how traffic demand modeling should be conducted under a scenario in which there is mixed traffic of CAVs and traditional drivers. They will be complemented with significant funding from private sector sources and contribute material research to intelligent transportation systems planning and installation.

How will you tell or show your results to others?

Our work will be disseminated through a comprehensive D-STOP report, through at least one paper for TRB and workshops at the TRB annual meeting. Further, it will be publicized on the CTR website and through various state and local level conferences when available.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Constantine Caramanis

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	Statistical Inference Using Stochastic Gradient Descent
Start Date	3/1/2017
Expected End Date	8/31/18

Why is this a problem or opportunity?

Many areas of machine learning and data mining focus on point estimates of key parameters. In transportation, however, the inherent variance, and, critically, the need to understand the limits of that variance and the impact it may have, have long been understood to be important. Indeed, variance and other risk measures that capture the cost of the spread around the mean, are critical factors in understanding how people act. Thus they are critical for prediction, as well as for purposes of long term planning, where controlling risk may be equally important to controlling the mean (the point estimate).

There has been tremendous progress on large scale optimization techniques to enable the solution of large scale machine learning and data analytics problems. Stochastic Gradient Descent and its variants is probably the most-used large-scale optimization technique for learning. This has not yet seen an impact on the problem of statistical inference -- namely, obtaining distributional information that might allow us to control the variance and hence the risk of certain solutions.

What are you going to do?

- The traditional approach for statistical inference, in the setting described above, is the use of the bootstrap and its variants. While this is a much-studied and also much-used tool, unfortunately it is not useful for large scale applications. As the data collected that enables smart transportation applications including planning, increases, this class of applications are also squarely in the "large scale" learning setting. Hence bootstrap and related approaches are increasingly inappropriate, due to their computational cost.
- We propose to develop ideas from Markov Chains and the large-scale optimization algorithm of choice, namely, Stochastic Gradient Descent (and variants), to develop a way to construct bootstrap samples without the bootstrap. Our preliminary experiments indicate that SGD with large (larger than typically prescribed) step size / learning rate, can produce samples that statistically seem nearly identical to bootstrap samples.
- We plan to make this observation rigorous, and show how it can be used in practice.

How will you involve graduate students?

Graduate students will be directly involved in the research. In particular, Tianyang Li, one of my current Ph.D. students, will be taking the lead on this project, though it will also have a contribution from Liu Liu, a junior Ph.D. student in my group.

How can your results be used?

These results will enable fast inference for large scale problems.

How will you tell or show your results to others?

We will publish papers on ArXiv for immediate open access and dissemination, and also in conference venues such as ICML, COLT, NIPS, and then journals such as the IEEE Trans on Info Theory.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Constantine Caramanis

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	Clustering and Classification
Start Date	4/1/2017
Expected End Date	9/1/18

Why is this a problem or opportunity?

Clustering is a fundamental methodology for transportation applications. This is true, in part, because we are trying to learn from and predict the behavior of a system that combines many different types of behaviors (drivers). Much about clustering, including fast rates of convergence, are still quite poorly understood.

What are you going to do?

We plan to investigate minimax bounds for classification and clustering error in the setting where co-variables are drawn from a mixture of two isotropic Gaussian distributions. Here, we define clustering error in a discriminative fashion, demonstrating fundamental connections between classification (supervised) and clustering (unsupervised). For both classification and clustering, our lower bounds show that without enough samples, the best any classifier or clustering rule can do is close to random guessing. For classification, as part of our upper bound analysis, we will attempt to show that Fisher's linear discriminant achieves a fast minimax rate $\Theta(1/n)$ with enough samples n . For clustering, as part of our upper bound analysis, in our work we would like to show that a clustering rule constructed using principal component analysis achieves the minimax rate with enough samples.

Our preliminary work suggests that something precisely along these lines may be true.

We will also seek to provide lower and upper bounds for the high-dimensional sparse setting where the dimensionality of the covariates p is potentially larger than the number of samples n , but where the difference between the Gaussian means is sparse.

How will you involve graduate students?

Graduate students will be directly involved by leading the research on this project.

How can your results be used?

These results are in the realm of fundamental methodology. We believe that they can lead to a more general agenda on appropriately understanding and applying clustering to large scale data mining applications.

How will you tell or show your results to others?

We will publish in open forums, conferences and journals. Also, the PI will give lectures on the results and their applications.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Sanjay Shakkottai

Name(s) of Proposed Collaborator(s):

Stephen Boyles

Project Info

Project Title	Bandit Algorithms for Online Learning and Resource Allocation
Start Date	01/01/2017
Expected End Date	08/31/2018

Why is this a problem or opportunity?

Online platforms are emerging as a powerful mechanism for matching resources to requests. In the setting of freight, the requests arrive from shippers, who have a diverse collection of goods. The resources are supplied by shippers (trucks), and have various physical constraints (driver's route preferences, carrying capacity, geographic preferences, etc.). Online platforms are emerging that (a) learn the characteristics of shippers and carriers, and (b) efficiently match goods to trucks based on such learning.

Our project will develop algorithms for such online resource allocation. This is a challenging problem, due to the complexity of the learning tasks. Such algorithms can have considerable impact on efficiently using trucking resources.

What are you going to do?

We will develop mathematical models for learning such complex tasks. There are several technical directions we will explore. First, we will develop low-dimensional latent models that can potentially simplify the sample complexity of such online learning. With such models, we will develop algorithms that exploit latent structure, as well as develop theoretical guarantees for these algorithms.

A second exciting direction we will pursue is to continually optimize the policy for making resource allocation decisions. The high-level idea is that policies “leak” information about other policies. Specifically, if the efficiency with a small collection of policies is understood, it is plausible that we can predict the behavior of other policies even when we have not implemented the others. We will explore formal mechanisms for leveraging such intuition, and develop algorithms for online policy optimizations.

How will you involve graduate students?

The research will be driven by graduate students. We expect that this work will also be an integral part of a student's Ph.D. dissertation.

How can your results be used?

This work, if successful has broad applicability. Beyond freight optimization, there are other settings in transportation networks and infrastructure networks (V2I setting) where continual improvement of policies is needed. Other algorithms and analysis would be an excellent starting point for such explorations.

How will you tell or show your results to others?

The work will be shared with the community through seminars, technical reports and conference/journal publications. We will also present this work to industry through open houses and poster sessions.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Sanjay Shakkottai

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	V2X Spectrum Resource Allocation for Sensing and Communications
Start Date	01/01/2017
Expected End Date	08/31/2018

Why is this a problem or opportunity?

It is expected that emerging wireless networks will be densified, and be able to support high throughput and low latency data along with infrastructure-supported sensing needs for vehicular traffic. Network densification, where dense overlapping spatial coverage is implemented using infrastructure nodes, is necessary to reliably support these needs. However, such densification will result in high energy usage, which is undesirable. We develop a research agenda for managing infrastructure node states for switching between active and inactive states to save energy, and when active, dynamically switching between sensing and communications to effectively serve both objectives (e.g. objectives being low latency for communications, and mean-square error for sensing fidelity).

In addition to fast time-varying channels, the challenge here is that mode switching incurs a penalty. When an infrastructure node's state changes (e.g. between active and inactive), there are penalties due to state migration, signaling to update V2I associations (a vehicle needs to be re-associated with some other infrastructure node), and related backhaul costs. Further, some of these operations have a hysteresis penalty as well (time lag due to such migration processes). This motivates the need for new scheduling mechanisms, that dynamically manage infrastructure nodes, and overall guarantees good network performance.

What are you going to do?

We will develop mathematical models for describing infrastructure modes, along with queueing modes to describe traffic demands. These models will be used to develop scheduling algorithms that optimize network performance with switching costs.

A novel aspect of this research will be in the use of online learning algorithms that work in synergy with the queue-length based scheduling algorithms. The learning algorithms will learn good activation and mode patterns over time, and continually work in tandem with the channel allocation algorithms to jointly optimize network goals.

The outcomes of this study will be new learning-cum-scheduling algorithms for V2I networks.

How will you involve graduate students?

The research will be driven by graduate students. We expect that this work will also be an integral part of a student's Ph.D. dissertation.

How can your results be used?

The algorithms from this research can be directly used in infrastructure nodes in emerging V2I networks. Managing modes of the infrastructure nodes is, we believe, a crucial challenge in V2I networks. Our work will thus be highly relevant for this setting.

How will you tell or show your results to others?

The work will be shared with the community through seminars, technical reports and conference/journal publications. We will also present this work to industry through open houses and poster sessions.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Chandra Bhat

Name(s) of Proposed Collaborator(s):

Project Info

Project Title	A New Microeconomic Theory-Based Model for Ranking Data
Start Date	5/1/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

One new paradigm of particular interest is the possibility of a mobility shift to heavy reliance on the preferences of individuals regarding market goods and services are typically imputed in choice models using consumer survey data. In such survey data, individual responses regarding goods and services may be elicited in one of several forms, though the most preferred alternative (or observed choice) is the one most commonly used. However, and especially when collecting stated preference data, another approach is to ask respondents to rank a set of alternatives from best to worst. While being as easy to collect as the most preferred alternative, rank-ordered data have the distinct advantage of presenting the ability to exploit the additional information to achieve a certain desired precision in choice model estimation with a much smaller sample size. However, there appears to be a conception that ranked data are not very reliable because of the cognitive demands placed on respondents in ranking several alternatives. This conception is based on consistent empirical findings of unstable coefficients based on the rank depth used in the typical rank-ordered logit (ROL) model. To salvage the ROL model, many researchers have modified it to accommodate what they believe to be increasingly more cognitive difficulty in ordering among lower-ranked alternatives than the higher-ranked alternatives, or allowing fundamentally changing decision protocols at different rank depths. More generally, all the ROL extensions originate in the notion that a rank-ordered response is a collection of sequential (and independent) decision-making processes in which the most preferred alternative is first chosen from all the available alternatives, then is excluded from the choice set followed by the choice of the second most preferred alternative, and so on until all the alternatives have been ranked. However, if the choice presentation setting is one in which a set of alternatives are all at once presented for ranking (which is the typical way that rank-ordered data are collected in surveys), these extensions of the ROL model are not consistent with the basic microeconomic theory driving discrete choice behavior. This is because, according to microeconomic theory, a respondent simultaneously evaluates all presented alternatives, with the rank-ordering being the manifestation of a joint preference relation across all alternatives. It just so happens that the ROL is consistent with both the microeconomic foundations of discrete choice as well as the top-down psychological model because of the IIA property, but the proposed ROL extensions to alleviate the problem of unstable coefficients across rank depths are not. At the same time, one can pin the empirical finding of unstable coefficients

across rank depths in the ROL to this same IIA property, rather than to any cognitive burden considerations. Thus, another way to deal with ranking data is to stay entrenched within the microeconomic foundation of discrete choice, but use a more general specification (than the independent and identically distributed extreme-value terms) for the kernel errors in the utilities of alternatives.

In this research, we discuss the importance of flexible specifications for the utility kernel error terms for rank-ordered data models. We also explain why, just like in the ROL, a mixed ROL that superimposes a distribution on the variable coefficients cannot be expected to resolve the problem of unstable coefficients across rank depths. Also, extending the mixed ROL in the ways that the ROL has been extended result in the corresponding models not being based on microeconomic theory. We instead adopt a finite-mixture approach to specify random coefficients on the variables as well as on the kernel error term, while using a multivariate normal distribution (including the kernel error term) within each mixture. As importantly, we propose the use of a robust composite marginal likelihood (CML) approach that guarantees estimator consistency under usual regularity conditions, while also entailing no more than the evaluation of bivariate cumulative normal distribution functions in the case of cross-sectional data, regardless of the number of random coefficients or number of alternatives. In the case of repeated ranking exercises, as is typical in stated preference surveys, we propose the MACML approach, which again entails the evaluation of no more than two-dimensional cumulative normal distribution functions. We demonstrate an application of our formulation and estimation approach to study bicycle commute route choice. The use of non-motorized modes for commuting presents many benefits both to society (reduction in congestion and vehicle emissions) and to the individual (health benefits from an active lifestyle). Therefore, encouraging the use of bicycles through the provision of adequate infrastructure is of vital importance. In order to better plan for such infrastructure, it is necessary to first understand how bicyclists make route decisions, what their preferences regarding route attributes (such as pavement condition, presence of big uphill, or travel time) are, and what determines such preferences.

What are you going to do?

The following tasks will be undertaken during the course of the project:

1. Develop the econometric formulation for finite-mixture ROL approach.
2. Develop an estimation approach for the proposed model.
3. Conduct an empirical application of the proposed model.
4. Discuss the main takeaways of our application and how they can be applied to transportation planning.

How will you involve graduate students?

Graduate students will modify a GAUSS code to estimate the proposed ranking data model and apply it to the bicycling route choice problem. During this process, students will need to develop a deep understanding of ranking models, as well as bicycle route data. Graduate students will also help write the related journal articles.

How can your results be used?

The results make evident the methodological and the empirical contribution of this study by showing the importance of flexible specifications for the utility kernel error terms for rank-ordered

data, while also providing important insights for bicycle infrastructure planning. In our study, we use data collected through a web-survey conducted in 2008 in the state of Texas, United States, to investigate the order of preference for ten different attributes in route choice: good pavement condition, avoidance of big uphill, quickest travel time, avoidance of stop signs and or stoplights, adequate lighting, safety from motor vehicles on the roadway, safety from collision with parallel parked vehicles, safety from collision with angle parked vehicles, and safety from crime. Insights on the importance of these attributes on bicyclers' route decisions can be directly applied to the bicycling infrastructure planning.

How will you tell or show your results to others?

We will submit articles for consideration for publication in leading transportation journals and present the research at national and international conferences (including the Transportation Research Board Meeting in Washington, D.C.).

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

Ming Zhang

Name(s) of Proposed Collaborator(s):

Chandra Bhat

Project Info

Project Title	Megaregional Trends of Passenger and Freight Movement: Evidence from National Transportation Data Sources
Start Date	05/15/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

In January 2017 USDOT designated thirteen Beyond Traffic Innovation Centers (BTICs) throughout the country. The BTICs set a clear focus on transportation research, education, and technology transfers in US megaregions. Megaregion is a concept originated from geography in the 1960's. The concept was rejuvenated at the turn of this century by urban and regional planners for spatial planning and research. The designation of BTICs signifies the prime time for transportation-centered megaregion research and policy making. UT Austin is home to one of the thirteen BTICs and is deemed to participate in and lead the megaregion efforts. The proposed research aims to study megaregional trends of passenger and freight movement by exploring national transportation databases and travel surveys. The research output is expected to help further conceptualize megaregion from the transportation planning perspective and identify trends and issues of megaregional mobility.

What are you going to do?

- Compile historic data sets on passenger and freight flows at the national, metropolitan, and county level. The main data sources include passenger and freight flows of surface and air transportation available since 2005 from the Bureau of Transportation Statistics; county-to-county freight movement data from TxDOT. National household travel surveys (NHTS) since 1995;
- Develop a data-mining frame consistent with the megaregion concept;
- Investigate and visualize passenger and freight flows;
- Draw implications of the study findings for national megaregional transportation investment and policy making and for state and regional transportation plans (e.g., Statewide Transportation Plan), with a focus on the Texas Triangle and the Gulf Coast megaregions.

How will you involve graduate students?

One doctoral student will be hired as GRA for the project.

How can your results be used?

Provide FHWA, BTICs, and state DOTs as well as individual MPOs in Texas and Louisiana with the study findings, which are expected to inform strategic megaregional and/or state-wide transportation planning.

How will you tell or show your results to others?

Submit one project report to D-STOP; submit 1–2 papers to Transportation Research Board annual meetings and for publication considerations.

D-STOP Research Problem Statement

Name of Proposed Principal Investigator:

James Kuhr

Name(s) of Proposed Collaborator(s):

Chandra Bhat, Natalia Ruiz

Project Info

Project Title	Transit Policy in the Context of New Transportation Paradigms
Start Date	9/1/2017
Expected End Date	9/30/2018

Why is this a problem or opportunity?

With changing transportation paradigms, there is significant potential for a shift in the balance between the overall population use of, and reliance on, ridesharing services versus traditional transportation options such as personal car ownership or transit use. This shift could lead to a realignment of the bulk of the responsibility for mobility to private entities and away from individual citizens and public entities. Today, as supplemental to the multitude of transportation options that are available, the availability, or lack thereof, of ridesharing services produces low to minimal risk to the traveling public. However, in a future in which ridesharing is optimally (widely) employed, the current independent nature of ridesharing services will influence wider community transit services. This problem statement explores the effects of new types of transportation on transit through the creation of several plausible future scenarios, and what policy decisions could potentially be made to ensure that transit is optimally employed.

What are you going to do?

Utilizing other D-STOP supported surveys (and potentially conducting our own as needed) that will identify attitudes towards ridesharing and various other methods of carpooling/car sharing that could serve as a competitor to transit services, we will work to analyze the potential effects of new transportation paradigms on transit system ridership. We will then identify key policy considerations for transit service providers in the next 10 years.

How will you involve graduate students?

These results will be used to help inform policy makers as to the role of transit in the next 10 years. The funding will be complemented with significant funding from private sector sources and contribute material research to the state of the art in long-range transportation planning.

How can your results be used?

These results will be used to help inform policy makers as to the role of transit in the next 10 years. The funding will be complemented with significant funding from private sector sources and contribute material research to the state of the art in long range transportation planning.

How will you tell or show your results to others?

Our work will be disseminated through a comprehensive D-STOP report, provided to major transit entities in the State of Texas and made widely available beyond that. Further, it will be publicized on the CTR website and through various state and local level conferences when available.