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## BEHAVIORAL URBAN INFORMATICS, LOGISTICS, & TRANSPORT LAB (BUILT@NYU) C2SMART University Transportation Center, New York University

### --- 2018 Research Brief ---

With the end of the year upon us, it is time to reflect on my lab’s research accomplishments this past year. Our lab specializes in “smart MaaS” research – data-driven, automated operations and decision support for a broad class of Mobility-as-a-Service systems. This year our lab concluded one grant and started two new grants from C2SMART in addition to two ongoing grants from NSF:

- City-scalable Destination Recommender System for On-demand Senior Mobility (C2SMART) (completed)
- Dual Rebalancing Strategies for Electric Vehicle Carsharing Operations (C2SMART) (initiated)
- Development of an open source multi-agent virtual simulation test bed for evaluating emerging transportation technologies and policies (C2SMART) (initiated)
- Urban Transport Network Design with Privacy-Aware Agent Learning (NSF CAREER CMMI-1652735) (ongoing)
- Stable matching of service tours to design cooperative policies for transport infrastructure systems (NSF CMMI-1634973) (ongoing)

Research collaborators include Prof. [Ozbay](#) and his team at C2SMART, Prof. [Jabari](#) at NYU Abu Dhabi, Prof. [Kelvin Cheu](#) at University of Texas, El Paso, Prof. [Xintao Liu](#) at HK Polytechnic, Prof. [Allahviranloo](#) at CCNY, and Dr. [Tai-Yu Ma](#) at [LISER](#). We have industry collaborations with [BMW ReachNow](#) and [NEXT Future Transportation](#).

BUILT participated in two summer research programs once again: the Summer Undergraduate Research Program at NYU, and the [ARISE program](#), which supports high school students interested in STEM research.

In addition, I completed a book entitled “[Informed Urban Transport Systems: Classic and Emerging Mobility Methods toward Smart Cities](#)” (#3). The book compiles research that I’ve conducted throughout my career in monitoring mobility, evaluating transport systems, and optimizing them in a dynamic setting. This compilation includes numerous examples and casts them within the context of classic transport methodologies. It serves as an all-in-one gateway for transport enthusiasts interested in tools and methods for designing and operating a wide range of classic and emerging mobility systems. The table of contents with brief description is provided:

#### PART A – Fundamentals

CHAPTER 1 – Urban Transport Systems: a discussion of classic frameworks for analysis transport systems, such as the Manheim-Florian-Gaudry framework, and how it is used for emerging mobility services

CHAPTER 2 – Monitoring Mobility in Smart Cities: various methods, due to the advances in Internet of Things and Big Data in Smart Cities, are presented, including new tools to analyze mobility patterns within a time geography context

#### PART B – Evaluation of Informed Systems

CHAPTER 3 – Network Equilibrium under Congestion: a vast range of methods are introduced to quantify and evaluate transport systems with congestion effects, including classic theories from Wardrop, Beckmann, and Vickrey, as well as newer concepts like two-sided markets

CHAPTER 4 – Market Schedule Equilibrium for Multimodal Systems: as mobile technologies connect mobility providers and smart cities with travelers, methods are presented to evaluate activity scheduling in a population with heterogeneous scheduling preferences, and using tools like MATSim

#### PART C – Learning from Public Information

CHAPTER 5 – Inverse Transportation Problems: machine learning customized to transportation network structures are introduced to monitor and infer system parameters over time



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CHAPTER 6 – Privacy in Learning: user and operator privacy concerns are addressed with methods in differential privacy and k-anonymity applied within network data objects

PART D – Design of Informed Systems

CHAPTER 7 – Network Design: tools for designing and operating networks are presented with numerous examples, including spanning trees, routing, facility location, Stackelberg games for designing road networks under congestion, and designing networks under coexisting systems

CHAPTER 8 – Network Portfolio Management: methods for designing networks dynamically under uncertainty are presented, including optimal timing, real options, and approximate dynamic programming

APPENDICES

- A. University Research Rankings
- B. Systems Engineering – covers systems engineering process, UML diagrams to communicate designs, and the use of simulation-based test plans to evaluate designs
- C. Queueing Analysis – covers Markov chains, M/M/s/k queues, M/G/1 queues, spatial queues, and Jackson networks
- D. Discrete Choice Modeling – covers consumer theory, random utility models, estimation, aggregation, market segmentation, and revenue management

**Research Highlights**

Our research agenda this year is divided into three thrust areas: learning/inference, systems evaluation, and dynamic optimization. All our products are open source. Prototypes of our algorithms can be found either online at <https://github.com/BUILTNYU> or by request. A recap of our research products in 2017 is available [here](#). Key findings in the three areas are presented.

***Transport system learning and informatics***

Susan Xu, my first PhD student at NYU, successfully defended her dissertation (#12) this month. Her work focuses on learning in capacitated multimodal networks. Two of her chapters remain to be published. One chapter solves the inference problem for **predicting which routes travelers make for vehicle sharing and similar systems**. These are complex because the links are not only capacitated, but the capacity effect is dynamic and dependent on flows of travelers on other links in the network (non-separable). The proposed route choice model relates the preferences of a traveler to different routes to the dynamic capacities which, in turn, relate to the flow patterns in the network. The discovery was presented at IATBR in Santa Barbara (#25).

A second objective is the design of a **privacy control mechanism to allow multiple operators to share network data** objects (like routes or pickup and drop-off locations) with each other and the public on an open data exchange by creating similar synthetic data. This discovery will allow MaaS and private company startup ecosystems to thrive by safely sharing data with each other without compromising their intellectual property. One paper was completed describing the breakthrough technology and is currently under review for publication.

A third objective is the **incorporation of multi-armed bandit algorithms, a type of reinforcement learning, into mobility services**. For new services, user data like preferences for destinations or the route under schedule constraints are often unknown in the first place. Without this, systems need an efficient learning mechanism that adequately serves users while efficiently gathering new sample data for estimating parameters. One such algorithm was developed for destination recommendation for mobility services with a prototype available on Github (#27). A working paper is being prepared for this technology based on the final report (#11) with additional numerical experiments to be published in a journal. A route selection algorithm was also developed for shuttle services to learn from real time travel information. Unlike multi-armed bandit algorithms in the literature, this one accommodates users’ schedule delay preferences. The technology will be presented at TRB (#8) and is under revision for publication in *Transportation Research Record*. We are now testing a new network design model for mobility operators to optimize where to set routes to learn the most from the deployment.



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Finally, earlier work with Prof. Xintao Liu to monitor travel momentum in a city using vector fields was applied to taxis in Beijing and was published earlier this year (#1).

### *MaaS evaluation*

Our work with developing an assignment model (see 2017 Research Brief) has advanced further. The original model, a many-to-one assignment game, allows a modeler to **design generalized cost sharing mechanisms such as combinations of fare pricing, access cost, wait time, and transfers, to ensure that routes are competitive with other operators**. Trade-offs can be made between route capacities of one operator with the pricing and performance of other operators. However, the model does not handle multimodal trips in which travelers use multiple operators to complete a trip. We have now devised a new model that can handle this issue (#19) and are testing it in several experiments. For example, it can be used to evaluate fare bundles for feeder systems or design shuttle services for closed transit routes like the L train shutdown in NYC. As an outcome of the earlier research, we are also developing a **dynamic cost allocation mechanism for microtransit services**. We are able to design the pricing bounds to use for dynamic route deviations that provide users with discounts (#20).

A second research objective is development of a **virtual test bed for citywide deployment evaluation of new transport technologies and policies**. Research and development for such technologies require a step between prototype development and field testing simply because of their public nature and heterogeneity of users from city to city. We have synthesized a population of 8 million for NYC and are in the process of calibrating a network in MATSim to simulate the travel of these individuals. This will provide a common platform and ecosystem to compare performances of different system designs, such as congestion pricing policies, transit route designs, emerging mobility services like carshare and robotic taxis, among others. Subsequent models for other cities like Seattle and El Paso will add to this “**Network of Living Labs**”.

NEXT Future Transportation is a prime example of an emerging transport technology: a **modular autonomous vehicle fleet where en-route vehicles can couple and decouple with each other**. Such technology can potentially improve public transit operations because it can reduce or eliminate transfers at stations, but how much so? The amount will vary from system to system and an evaluation methodology is needed. Nick Caros studied this problem for his MS thesis (#14), which led to a paper presented at the hEART Conference in Athens, Greece (#22), and has been submitted to a journal for publication. We designed a new simulation technology that extends from earlier work to evaluate the operator’s learning mechanism to set the appropriate weights between user cost and operator cost to optimize their profit. It was tested in a case study drawn from a commuter route between Dubai and Sharjah.

### *Dynamic network optimization*

Our earlier discoveries with dynamic relocation of idle vehicles drew the attention of BMW ReachNow, who agreed to share their carshare data with us. In our C2SMART project, we developed a new relocation technology that handles two sets of requirements: unbalanced demand and electric vehicle (EV) charging. Our technology uniquely handles **EV charging relocations and uses the look-ahead approximation** from earlier discoveries to optimize the performance. Preliminary results were promising and will be presented at TRB in 2019 (#4). We are now testing the technology on the data to provide recommendations on EV adoption, which are applicable to other carshare and EV mobility services.

The collaboration with Dr. Tai-Yu Ma continues. We developed a new **operating policy for dispatch-routing-relocation of rideshare services that make use of co-existing public transit capacity**. It is a more generalized form of using rideshare as a transit feeder service, as passengers may be intentionally dropped off at transit stations to take to another station from which another rideshare vehicle would be assigned to pick up. While the transfers would intuitively deter passenger demand, this is found to be offset by the additional available rideshare vehicles that end up near stations, an effect of the added transit capacity. Using the rideshare service in NYC and Long Island with the LIRR commuter rail capacity, we found that it makes the average available fleet increase four times for the same demand level. The discovery has been presented at IATBR and INFORMS (#21) and a working paper is available on arXiv (#15).



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In a collaboration with Prof. Allahviranloo, we studied the problem of operating a **market for an autonomous car club**. Ownership in autonomous car clubs would be shared between multiple owners much like publicly traded stocks. Ownership takes the form of time slots for which an owner would be transported along their activity schedule and trading such slots depends on the schedule elasticity of the owners (an owner that needs a vehicle between 8-9AM would be forced to pay a higher premium than someone whose schedule is more flexible). We developed a decision support model to design the fleet size and set pricing for these time slots in an open market of users with heterogeneous activity schedule preferences. The design is tested with user schedule data from NYC and shown to be more effective than a naïve pricing model (#2).

**Looking Ahead**

Some of our efforts are now picking up steam and I anticipate 2019 to be a big year with many exciting new announcements. We hope that these advances will bring us closer to becoming the preeminent source in the U.S. for smart MaaS technological solutions and policy support.

Lastly, BUILT will once again be present at the TRB reception from NYU Tandon School of Engineering and C2SMART, which will be hosted at the Marriott Marquis Treasury Room (M4) on Sunday, January 7<sup>th</sup>, 5-7PM ([RSVP here](#)). We hope to see friends and colleagues there!

Sincerely,

Joseph Chow, Ph.D., P.E.

[Assistant Professor, Department of Civil & Urban Engineering](#)  
[Deputy Director, C<sup>2</sup>SMART University Transportation Center](#)  
[BUILT@NYU](mailto:BUILT@NYU)

New York University

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**BUILT Lab members active in 2018**

**PhD student researchers**

[Susan Jia Xu](#), [Jinkai Zhou](#), [Yueshuai Brian He](#), [Saeid Rasulkhani](#), [Gyugeun Yoon](#), [Ted Pantelidis](#), [Qi Liu](#), [Reuben Juster](#), [Anthony Haoran Su](#), [Jesse Fu](#)

**MS student researchers**

[Assel Dmitriyeva](#), [Nick Caros](#), [Patrick Scalise](#)

**Undergraduate student researchers**

[Ziyi Ma](#), [Eric Gan](#), [Carol Shlyakhova](#)

**New Research Products in 2018**

***Journal publications:***

- 1) **Liu, X., Chow, J.Y.J.**, Li, S., 2018. Online monitoring of taxi travel momentum and congestion effects using projections of taxi GPS-based vector fields, *Journal of Geographical Systems* 20(3), 253-274.
- 2) Allahviranloo, M. and **Chow, J.Y.J.**, 2019. A fractionally owned autonomous vehicle fleet sizing problem with time slot demand substitution effects. *Transportation Research Part C: Emerging Technologies*, 98, pp.37-53.



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**Books:**

- 3) **Chow, J.Y.J.**, 2018. *Informed Urban Transport Systems: Classic and Emerging Mobility Methods Toward Smart Cities, 1<sup>st</sup> Ed.* Elsevier, Amsterdam, The Netherlands.

**Conference proceedings:**

- 4) Ma, T.Y., **Pantelidis, T.**, **Chow, J. Y. J.**, 2019. Optimal queueing-based rebalancing for one-way electric carsharing systems with stochastic demand. Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 5) Khan, S.A.K., Bierds, W., Bringardner, J., **Chow, J. Y. J.**, 2019. Adapting the business model canvas entrepreneurship tool to assist transportation technology transfer. Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 6) Jung, J., **Chow, J.Y.J.**, 2019. Effects of charging infrastructure and non-electric taxi competition on electric taxi adoption incentives in New York City. Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 7) Abou Kasm, O., **Ma, Z.**, **Chow, J.Y.J.**, Diabat, A., 2019. Quantifying the effect of cyclist behavior on bicycle crashes and fatalities. Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 8) **Zhou, J.**, **Lai, X.**, **Chow, J. Y. J.**, 2019. Multi-armed bandit on-time arrival algorithms for sequential reliable route selection under uncertainty, Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 9) **Caros, N.**, **Chow, J. Y. J.**, 2019. Effects of violent crime and vehicular crashes on active mode choice decisions in New York City, Proc. 98<sup>th</sup> Annual Meeting of the TRB, Washington, DC.
- 10) Cheu, R.L., Villanueva-Rosales, N., Nunez-Mchiri, G.G., Vechione, M., Vargas-Acosta, R.A., Marrufo, C., Jimenez-Velasco, M.G., Gurbuz, O., **Dmitriyeva, A.**, **Chow, J.Y.J.**, 2018. Bringing smart mobility services to seniors: challenges and solutions in El Paso, TX, and New York, NY, ISC2.

**Research reports:**

- 11) *City-scalable Destination Recommender System for On-demand Senior Mobility*, Sponsor: C<sup>2</sup>SMART UTC.

**Dissertations and Theses completed/advised:**

- 12) **Xu, J.S.**, 2019. *Learning in capacitated multimodal networks over time*. PhD dissertation, New York University.
- 13) Melnick, L., 2018. *A dynamic ridesharing routing algorithm with en-route transfers*, MS thesis, New York University.
- 14) **Caros, N.**, 2019. *Dynamic operations of a mobility service with en-route transfers*. MS thesis, New York University.

**Working papers:**

- 15) Ma, T. Y., **Rasulkhani, S.**, **Chow, J. Y. J.**, Klein, S., 2018. An integrated dynamic ridesharing dispatch and idle vehicle repositioning strategy on a bimodal transport network, arXiv.

**Invited Talks:**

- 16) “Evaluation of Mobility-as-a-Service Alternatives”, The Hong Kong Polytechnic University, Nov 23, 2018.
- 17) “City-scalable destination recommender system for on-demand senior mobility”, NSF Research Coordination Network: Smart & Connected Communities and Aging Population, Apr 20, 2018.
- 18) “Privacy control strategies to support Mobility-as-a-Service”, Erasmus University Rotterdam, Apr 9, 2018.

**Conference Presentations:**

- 19) “A many-to-many stable matching cost allocation model for multimodal Mobility-as-a-Service”, INFORMS, Phoenix, AZ, Nov 4-7, 2018.
- 20) “Dynamically stable route deviation and user-operator cost allocation for a flexible transit service”, INFORMS, Phoenix, AZ, Nov 4-7, 2018.
- 21) “An integrated dynamic ridesharing dispatch and idle vehicle repositioning strategy on a bimodal transport network”, INFORMS, Phoenix, AZ, Nov 4-7, 2018.
- 22) “Evaluation of last-mile transit operations with en-route transfers”, hEART Conference, Athens, Greece, Sept 5-7, 2018.



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- 23) “An integrated dynamic ridesharing dispatch and idle vehicle repositioning strategy on a bimodal transport network”, IATBR, Santa Barbara, CA, July 15-20, 2018.
- 24) “Effect of routing constraints on learning in contextual bandit mobility-on-demand destination recommendation systems”, IATBR, Santa Barbara, CA, July 15-20, 2018.
- 25) “Modeling non-separable, social-influenced multimodal route choice with congestible link capacities”, IATBR, Santa Barbara, CA, July 15-20, 2018.

***Prototypes and data:***

**PROTOTYPES:**

- 26) <https://github.com/BUILTNYU/Monitoring-Bus-Arrivals-for-Headway-Control-Strategies>: tool for extracting bus locations from MTA’s BusTime and monitoring delay by constructing a cumulative arrival diagram in real time
- 27) <https://github.com/BUILTNYU/recommender-system>: destination recommender system for mobility services to learn and recommend destinations to users

**DATA:**

- 28) <https://github.com/BUILTNYU/BeijingTaxiVectorField>: a visualization of a vector field constructed for taxis in Beijing over the course of a day
- 29) <https://github.com/BUILTNYU/UAVtrafficmonitoring>: test instances for a stochastic dynamic arc inventory routing problem used for deploying UAVs for traffic monitoring
- 30) [https://github.com/BUILTNYU/data\\_bimodal\\_ridesharing](https://github.com/BUILTNYU/data_bimodal_ridesharing): data for a case study evaluating an operating strategy for a rideshare service to make use of the Long Island Railroad to serve travel demand in Long Island