



NYU

TANDON SCHOOL OF ENGINEERING



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

### --- 2019 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, continued another two grants into their second year phase, and started a new grant from C2SMART. We continued work on two ongoing grants from NSF and initiated a new project with the Federal Transit Administration. NYU Abu Dhabi initiated a new [CITIES center](#) which we are involved in with Prof. Jabari. We initiated a new [on-call agreement](#) with NYS DOT through C2SMART.

- Dual Rebalancing Strategies for Electric Vehicle Carsharing Operations (**C2SMART**, joint with Prof. Jabari) (completed)
- Development of an open source multi-agent virtual simulation test bed for evaluating emerging transportation technologies and policies Year 2: Development and tech transfer of multi-agent virtual simulation test bed ecosystem (**C2SMART**, joint with Prof. Ozbay) (ongoing)
- Urban Connector Senior Mobility App Year 2: Field Tests (**C2SMART**, joint with Prof. Cheu) (ongoing)
- Simulation and analytical evaluation of bus redesign alternatives in transit deserts with ride-hail presence (**C2SMART**, joint with Dr. Goldwyn) (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 – one year no cost extension)
- Synthesis of real time public transit route deviation operational policies (**FTA NY-2019-069-01-00**) (initiated)
- **CITIES Center** research on urban shared mobility systems (joint with Prof. Jabari)
- **NYS DOT** on-call agreement with C2SMART

Research collaborators include Prof. [Ozbay](#) and his team at C2SMART, Prof. [Jabari](#) and Prof. [Menendez](#) at NYU Abu Dhabi, Dr. [Eric Goldwyn](#) at NYU Marron Institute, Prof. [Kelvin Cheu](#) at University of Texas, El Paso, Prof. [David Watling](#) at University of Leeds, Prof. [Song Gao](#) at UMass Amherst, Prof. [Oded Cats](#) at TU Delft, Prof. [Xintao Liu](#) at HK Polytechnic U., and Dr. [Tai-Yu Ma](#) at [LISER](#). Our industry collaboration with [BMW ReachNow](#) concluded with the C2SMART project and we started a collaboration with the [World Economic Forum](#) as a member of the [Global Network Mobility Coalition](#).

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.

### **Research Highlights**

Our research agenda this year is divided into two thrust areas: (1) learning/inference with dynamic network optimization and (2) MaaS systems evaluation. 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 2018 is available [here](#). Key findings in the two areas are presented.

### ***Dynamic transport system learning and network optimization***

The research in this thrust deal with designing algorithms for systems in an online setting, where design decisions (e.g. routing, dispatch, positioning) are interdependent with learning efforts. Our concentration this year was on **incorporating learning algorithms based on contextual bandit problems into mobility systems**, following our work from last year. Jinkai Zhou's work on sequential route selection using multi-armed bandit was published this year. Gyugeun Yoon led the effort in integrating contextual bandit learning with destination recommendation, which



NYU

TANDON SCHOOL  
OF ENGINEERING



led to the development of an app feature over the summer for recommending restaurants to seniors based on Yelp reviews. The work on destination recommendation is currently under revision in a journal and was presented at Western Michigan. Gyugeun further incorporated the learning methodology into **route generation for transit network design**. The goal is to construct the artificial intelligence (AI) for automated mobility services to organically grow their routes to best serve customers. That work has been accepted for presentation at TRB and recently at INFORMS in Seattle. The simulation platform used to evaluate the mobility services was used in competition at the IATR Microtransit Hackathon and helped the team [win first place](#).

With the completion of our C2SMART project with Prof. Jabari for the electric vehicle (EV) rebalancing algorithm development using BMW data, Ted Pantelidis developed a unique **EV rebalancing heuristic that can operate effectively in an online setting**. The algorithm includes **look-ahead approximation**. The research was presented at the TSL Workshop in Vienna, Austria, and at INFORMS in Seattle. To test the algorithm, we also developed an **agent simulation** with Li Li that has been presented at IEEE ITSC in Auckland, New Zealand. We are preparing the final manuscript to submit to a journal special issue.

Susan Xu's last two dissertation chapters, which deal with **online inference for capacitated Mobility-as-a-Service (MaaS) systems** and **validation of the network learning methodology**, have both been accepted for presentation at the upcoming 99<sup>th</sup> TRB Annual Meeting (the former with Prof. Song Gao). The validation work with Qian Xie (when she was still an undergrad visiting student from Tsinghua prior to joining as a PhD student with Prof. Li Jin) takes taxi breadcrumb data from Wuhan, China, and shared by Prof. Xintao Liu, to demonstrate that applying sensors to monitor routes chosen between *even only 2 origin-destination (OD) pairs* the system can be quite effective.

The **privacy control mechanism for data sharing among MaaS operators** with PhD student Brian Yueshuai He has now been published as well and was presented at ISTTT23 in Lausanne, Switzerland over the summer.

The work with Dr. Tai-Yu Ma on developing an **operating policy for rideshare services with coexisting public transit** has been published.

### ***MaaS evaluation***

The foremost priority in this thrust is our work with developing a MaaS assignment model (see 2018 Research Brief), which has advanced further. The original model, a **many-to-one assignment game** was published this year and was applied to a microtransit service (Kussbus) in Luxembourg through collaboration with Dr. Tai-Yu Ma. We have since built on this work significantly. Saeid Rasulkhani and Ted Pantelidis developed a generalized many-to-many assignment game model that can determine stable outcomes for **multiple MaaS operators cooperating to provide multimodal service to a traveler**, under a specialized case of a completely decentralized system and a broader case. For example, the model allows us to evaluate the following types of scenarios: network duopoly vs monopoly vs decentralized market; government acquisition of an operator; firm entry; capacity increase effect on MaaS market; and technological change. Both studies were accepted for presentation at the upcoming TRB Annual Meeting and were presented at TRISTAN X and INFORMS in Seattle. Saeid successfully defended his dissertation (with Prof. Watling as an external committee member) based on this topic, which also includes a final chapter that considers the cost allocation problem for a single platform in a market consisting of multiple platforms. A platform in this case is any submarket manager that matches operators with travelers; it can be a mobility app like Uber or Scoop, or it can be a city agency that adjusts its built environment as the platform. Earlier work assumed a platform managed the whole mobility market, but in many cases this might not be true, and platforms may have to deal with competition from other platforms as well. Our work in this area and in the data privacy led to our collaboration with the World Economic Forum on the production of policy toolkit for shared, electric, and automated mobility ([SEAM](#)).

Within the MaaS setting, the consideration of cost allocations is also made under uncertainty. This work led by Ted, and in collaboration with Prof. Oded Cats, casts the cost allocation problem as a two-stage stochastic programming model in order **to design insurance contracts between multiple operators**. The contracts would stipulate that in



NYU

TANDON SCHOOL  
OF ENGINEERING



the scenario that a disaster disrupts an operator's service capacity, they can borrow a certain amount of resources from other operators to compensate. The insurance premiums paid by each operator would therefore depend on their market power with respect to the others, the types of disruption scenarios and whom they affect; and the existing service capacities and market demand structure. For example, it would allow a public transit agency to create an agreement with a private microtransit provider like Via to ensure that if the transit links get disrupted they can get a fair price on using capacity provided by Via.

A second major research objective is the 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 synthesized a population of 8 million for NYC that includes smartphone ownership and probability of using bikeshare and for-hire vehicles. The population has been used to evaluate the effects of **Citi Bike expansion** in NYC and the hypothetical location of **Amazon's second headquarters in Long Island City**. It has also been used to support other research and Capstone projects at CUSP. A paper was submitted to a journal for review. Following the synthetic population development, we have completed the calibration of the network for simulating the daily trips in MATSim. 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. The simulation is being used to evaluate [congestion pricing scenarios for NYC](#), with preliminary results suggesting that revenues need to be distributed more heavily towards services in the outer boroughs to compensate for the costs imposed on their travelers. A paper is now being prepared. One example application of the test bed has been on [bus network redesigns](#) that the MTA has been so interested in doing in NYC boroughs with the help of software providers like Remix. With the use of our tools, we can provide a much more comprehensive assessment of service operations, including ridership and welfare impacts for Dr. Goldwyn's [proposed network redesign](#) for Brooklyn. Jinkai Zhou is also testing the use of MATSim along with a surrogate model algorithm to design deployment coverage for automated vehicle fleets in NYC.

Our lab has made several contributions to evaluation of emerging technologies. As continuation from the previous year, Nick Caros' work on evaluating **modular autonomous vehicle fleets** (e.g. [NEXT](#)) has been accepted for presentation at the upcoming TRB Annual Meeting and is in preparation for a paper submission. Srushti Rath studied urban air mobility and **designed skyport infrastructure** to support air taxis serving customers to access NYC airports and is under revision in a journal. Mina Lee studied **e-scooters** and developed a forecast model to best relate e-scooter trips in NYC to existing trips that include access/egress trips to public transit and is in preparation for a paper submission. The latter two studies were presented at the NYIT Transportation Technology Summit as well as the upcoming TRB Annual Meeting.

### **Looking Ahead**

The last year has seen my lab's work focus on three major efforts: the integrated learning/optimization for transit, MaaS market evaluation using cooperative game theory, and technology evaluation using a virtual test bed connected to MATSim. These efforts are gaining us more attention and collaboration with partners in upcoming projects; we anticipate a few major research products next year solidifying our position in a MaaS institute. The virtual test bed is being integrated into upcoming projects and should see increasing interest from public agencies to quickly assess citywide effects of emerging technologies and policies.

Sincerely,

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

[Assistant Professor, Department of Civil & Urban Engineering](#)  
[Deputy Director, C2SMART University Transportation Center](#)  
[BUILT@NYU](mailto:BUILT@NYU)

New York University



NYU

TANDON SCHOOL OF ENGINEERING



\*\*\*\*\*

**BUILT Lab members active in 2019**

**PhD student researchers**

[Jinkai Zhou](#), [Yueshuai Brian He](#), [Saeid Rasulkhani](#), [Gyugeun Yoon](#), [Ted Pantelidis](#), [Qi Liu](#), [Jesse Fu](#), [Bingqing Chloe Liu](#)

**MS student researchers**

[Ziyi Ma](#) (Eisenhower Fellow), [Srushti Rath](#), [Mina Lee](#), [Nicolas Gomez Rojas](#), [Patrick Scalise](#), [Shams Sahar](#) (Fulbright Scholar)

**Undergraduate student researchers**

[Alicia Luo](#), [Sara Alanis](#), [Matthew Shen](#)

**New Research Products in 2019**

***Journal publications:***

- 1) **Caros, N. S., Chow, J. Y. J.**, 2020. Effects of violent crime and vehicular crashes on active mode choice decisions in New York City, *Travel Behavior and Society*, 18, 37-45.
- 2) **Xu, S. J., Chow, J. Y. J.**, 2019. A longitudinal study of bike infrastructure impact on bike-share system performance in New York City. *International Journal of Sustainable Transportation*, in press, doi: [10.1080/15568318.2019.1645921](https://doi.org/10.1080/15568318.2019.1645921).
- 3) Ma, T. Y., **Rasulkhani, S., Chow, J. Y. J.**, Klein, S., 2019. A dynamic ridesharing dispatch and idle vehicle repositioning strategy with integrated transit transfers. *Transportation Research Part E* 128, 417-442.
- 4) **He, B. Y., Chow, J. Y. J.**, 2019. Optimal privacy control for transport network data sharing. *Transportation Research Part C*, SI: ISTTT23, in press, doi: [10.1016/j.trc.2019.07.010](https://doi.org/10.1016/j.trc.2019.07.010).
- 5) **Rasulkhani, S., Chow, J.Y.J.**, 2019. Route-cost-assignment with joint user and operator behavior as a many-to-one stable matching assignment game. *Transportation Research Part B* 124, 60-81.
- 6) **Zhou, J., Lai, X., Chow, J. Y. J.**, 2019. Multi-armed bandit on-time arrival algorithms for sequential reliable route selection under uncertainty. *Transportation Research Record*, 2673(10), 673-682.
- 7) 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. *Transportation Research Record* 2673(4), 262-274.

***Conference proceedings:***

- 8) **Caros, N. S., Chow, J. Y. J.** (2020). Day-to-day market evaluation of last-mile transit operations using modular autonomous vehicles with en-route transfers, 99th Annual Meeting of the TRB, Washington, DC.
- 9) **Xu, S. J., Xie, Q. J., Chow, J. Y. J., Liu, X.** (2020). Empirical validation of network learning with taxi GPS data from Wuhan, China, 99th Annual Meeting of the TRB, Washington, DC, <https://arxiv.org/abs/1911.03779>.
- 10) **Pantelidis, T., Rasulkhani, S., Chow, J.Y.J.** (2020). A path-based many-to-many assignment game to model Mobility-as-a-Service market networks, 99th Annual Meeting of the TRB, Washington, DC, <https://arxiv.org/abs/1911.04435>.
- 11) **Xu, S. J., Chow, J. Y. J., Gao, S.** (2020). Online route choice modeling for Mobility-as-a-Service networks with non-separable, congestible link capacity effects, 99th Annual Meeting of the TRB, Washington, DC, <https://arxiv.org/abs/1912.09004>.
- 12) **Rasulkhani, S., Pantelidis, T., Chow, J. Y. J.** (2020). A many-to-many assignment game method to evaluate cost allocations of link operators in a Mobility-as-a-Service market without route enumeration, 99th Annual Meeting of the TRB, Washington, DC.
- 13) **Lee, M., Chow, J.Y.J., Yoon, G., He, B.Y.** (2020). Forecasting e-scooter competition with direct and access trips by mode and distance in New York City, 99th Annual Meeting of the TRB, Washington, DC <https://arxiv.org/abs/1908.08127>.



**NYU**

**TANDON SCHOOL  
OF ENGINEERING**



- 14) Dakic, I., Yang, K., Menendez, M., **Chow, J.Y.J.** (2020). Flexible bus dispatching system with modular and fully automated bus units, 99th Annual Meeting of the TRB, Washington, DC.
- 15) **Yoon, G., Chow, J. Y. J.** (2020). Reinforcement learning-based sequential transit route design under demand uncertainty, 99th Annual Meeting of the TRB, Washington, DC.
- 16) Li, L., Lin, D., **Pantelidis, T.**, Jabari, S. E., **Chow, J. Y. Y.** (2019). An agent-based simulation for shared automated electric vehicles with vehicle relocation. IEEE ITSC 2019, Auckland, NZ.
- 17) Jung, J., **Chow, J. Y. J.** (2019). Large-scale evaluation of fleet repositioning strategies for dynamic rideshare in New York City, SAE conference.
- 18) **He, B.Y., Chow, J. Y. J.** (2019). Optimal privacy control for transport network data sharing, ISTTT23, Lausanne, Switzerland.

**Research reports:**

- 19) *Dual Rebalancing Strategies for Electric Vehicle Carsharing Operations*, PI: J.Y.J. Chow, co-PI: S.E. Jabari; Sponsor: C2SMART UTC.

**Dissertations and Theses completed/advised:**

- 20) **Rasulkhani, S.**, 2020. *Stable matching evaluation and platform design for Mobility-as-a-Service markets*. PhD dissertation, New York University.
- 21) **Rath, S.**, 2020. *Infrastructure planning for urban air mobility*, MS thesis, New York University.

**Working papers:**

- 22) Ma, T.Y., **Chow, J. Y. J.**, Klein, S., **Ma, Z.**, 2019. A stochastic user-operator assignment game for empirical evaluation of a microtransit service in Luxembourg. Arxiv: <https://arxiv.org/abs/1912.01984>.

**Invited Talks:**

- 23) Panelist at NEEP 2019, “Electric Mobility in the New Smart City”, Brooklyn, NY: <https://twitter.com/nyutandon/status/1166695306244829184>.
- 24) “Planning for Mobility-as-a-Service: Decoupling the incentives of travelers and operators for smart cities”, Next Gen Mobility Summit, Silicon Valley, CA, May 24, 2019.
- 25) “Overcoming obstacles to an electric mobility future”, BEST Workshop, Industry-University Cooperative Research Centers Program, NSF, New York City, April 5, 2019.
- 26) “Evaluating emerging transportation technologies and policies with a ‘Network of Living Labs’”, National Socio-Environmental Synthesis Center Workshop, Annapolis, MD, Feb 22, 2019.

**Conference Presentations:**

- 27) “Forecasting e-scooter competition with direct and access trips by mode and distance in New York City”, UTRC-NYIT Transportation Technology Summit, New York, Nov 1, 2019.
- 28) “Air Taxi Skyport Location Problem for Airport Access”, UTRC-NYIT Transportation Technology Summit, New York, Nov 1, 2019.
- 29) “Dynamic on Demand Ride-sharing Trip-vehicle Matching with Pricing”, INFORMS Annual Meeting, Seattle, WA, Oct 20-23, 2019.
- 30) “Sequential Line Planning Problem With Integrated Learning For Emerging Mobility Routes”, INFORMS Annual Meeting, Seattle, WA, Oct 20-23, 2019.
- 31) “Online Rebalancing Algorithms For Electric Car-sharing Systems”, INFORMS Annual Meeting, Seattle, WA, Oct 20-23, 2019.
- 32) “Doubly-constrained rebalancing for one-way electric carsharing systems with capacitated charging stations”, 7th TSL Workshop, Vienna, Austria, July 15-18, 2019.
- 33) “A many-to-many stable matching cost allocation model for multimodal Mobility-as-a-Service”, TRISTAN X, Hamilton Island, Australia, June 17-21, 2019.
- 34) “Integration of recommender system in mobility services to improve seniors’ accessibility”, 6th Annual Summer Conference on Livable Communities in Western Michigan University, June 7, 2019.

**Prototypes and data:**



NYU

TANDON SCHOOL  
OF ENGINEERING



- 35) [https://github.com/BUILTNYU/multimodal\\_route\\_choice](https://github.com/BUILTNYU/multimodal_route_choice): data for testing multimodal route choice with congestible capacities
- 36) <https://github.com/BUILTNYU/IO-Validation>: Wuhan taxi trajectory data for testing network learning method using
- 37) <https://github.com/BUILTNYU/BMWproject>: data and code for the heuristic and its evaluation using Brooklyn carshare data
- 38) <https://github.com/BUILTNYU/restaurantRecoSystem>: restaurant recommender system code and sample data for recommending restaurants to users