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

--- 2020 Research Brief ---

This year's research brief reflects on one of the most tumultuous years in our lifetimes. As transportation scientists, we naturally seek to improve society through our work, and the arrival of COVID-19 not only impacted our personal lives but also gave us pause on our ongoing efforts and consider their outcomes under a new light. Our lab continued to produce research products this year in our area of specialization of "smart MaaS" research – data-driven, automated operations and decision support for a broad class of Mobility-as-a-Service systems. As we did so, however, we also found ways to direct some of our work towards addressing new challenges from COVID.

Our lab completed one NSF grant, one grant for the FTA, and two grants from C2SMART. We started a new grant with C2SMART, a task with NYSDOT, and an EAGER grant with NSF. We are also a collaborator with the team that was awarded a grant from FNR in Luxembourg.

- Urban Microtransit Cross-sectional Study for Service Portfolio Design (**C2SMART**, joint with Dr. Zimmerman from Rudin Center in collaboration with Via Rideshare)
- EAGER/Collaborative Research: Enable elastic capacity for transportation infrastructure through a transmodal modular autonomous vehicle system (**NSF CMMI-2022967**, as a co-PI with lead PI Prof. X. Li from USF)
- NYS DOT on-call agreement Task: Statewide Mobility Serivces Program Strategic Procurement Planning (**NYSDOT SR-20-02**)
- Urban Transport Network Design with Privacy-Aware Agent Learning (**NSF CAREER CMMI-1652735**) (ongoing)
- M-EVRST (Multimodal Electric Vehicle demand ReSponsive Transport) (**FNR**, as a collaborator with PIs Dr. T.Y. Ma/LISER and Prof. F. Viti/U. Luxembourg)
- 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) (completed)
- Simulation and analytical evaluation of bus redesign alternatives in transit deserts with ride-hail presence (**C2SMART**, joint with Dr. Goldwyn) (completed)
- Stable matching of service tours to design cooperative policies for transport infrastructure systems (**NSF CMMI-1634973**) (completed)
- Synthesis of real time public transit route deviation operational policies (**FTA NY-2019-069-01-00**) (completed)

Research collaborators include Prof. Ozbay and his team at C2SMART, Dr. Eric Goldwyn at NYU Marron Institute, Prof. Oded Cats at TU Delft, Dr. Tai-Yu Ma at LISER, Prof. Xiaopeng Li at University of South Florida, and Oliver Gao at Cornell/CTECH. We have a new industry collaboration with Via through a C2SMART project.

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 briefs from 2015 – 2019 can be found here.

Research Highlights

Our research agenda this year is divided into two main thrust areas: (1) learning/inference with dynamic network optimization and (2) MaaS systems evaluation. A third thrust area emerged from the second, involving the development of a virtual test bed for evaluating citywide travel impacts of emerging technologies and policies. All our products are open source. Prototypes of our algorithms can be found either online at https://github.com/BUILTNYU or by request. Key findings 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. Gyugeun Yoon continues to develop an integrated network design and optimal learning algorithm. He presented his latest findings at the 2020 INFORMS Annual Meeting held virtually this year. The goal is to construct the artificial intelligence (AI) for automated mobility services to organically grow their routes to best serve customers as a sequential decision process. Earlier efforts made use of contextual bandit algorithms to make decisions that include learning. Due to correlated network effects, we are now exploring the use of knowledge gradients.

Qi Liu developed a new **transit passenger flow estimation** model that makes use of stop count data that is sensitive to transit schedules. The model was tested on a portion of the Shanghai Metro and shown to be effective.

In the research for modular autonomous vehicles (MAVs), Zhexi Fu developed an optimization model and algorithm for routing vehicles that consider **en-route synchronized transfers**. The difference from the literature is that this new work synchronizes transfers for passengers, so no one is assumed to have to wait outside a vehicle at a transfer stop.

MaaS evaluation

The foremost priority in this thrust is our work with developing a MaaS assignment model. Ted Pantelidis and Saeid Rasulkhani 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**. 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. The framework was applied in collaboration with LISER to a microtransit service in Luxembourg, Kussbus, and we correctly surmised that its operation was unsustainable.

Microtransit remains a controversial mode as the success in operation can vary significantly, with many examples of high-profile failures due to high costs and low ridership. In a study for the FTA, we compiled a literature on microtransit in the context of public transit operations planning and further developed a **generic, open source simulation software** that practitioners can use to compare between fixed route and microtransit services for any given study area. From that initial work, we are now collaborating with Via to develop simulation-based models that evaluate the equilibrium ridership for microtransit services in six cities in the U.S., based on the day-to-day adjustment framework developed earlier by Shadi Djavadian and Nick Caros. These simulations will be used to inform deployments of microtransit in any region of any city in the U.S.

In the case where MaaS data is limited, a public agency may still wish to forecast a distribution of passenger and vehicle trips. Brian Yueshuai He **generalized the classic gravity model** to handle multi-operator services supporting passenger trips that may be shared or as part of a series of trip chains. The model was tested using the Chicago Uber data set which uniquely includes shared ride trips.

Bingqing Liu took the online route choice model with congestible link capacities that Susan Jia Xu initially worked on and derived a steady state equilibrium model for MaaS networks. The model is a **stochastic user equilibrium with congestible link capacities** based on earlier work by Michael Bell, but the presence of congestible, non-separable link capacity effects required a new solution method.

In a project using Queens bike count data from NYCDOT, Bingqing estimated a **bike count forecast model that captures multimodal network connectivity** using a measure derived from path queries with Open Trip Planner. We found that the measure is indeed statistically significant, which can help policymakers relate bike demand to the bike and transit infrastructure.

NYC Department of Citywide Administrative Services (DCAS) is currently planning out their fast DC electric charging infrastructure (can recharge a vehicle in a half hour) in support of the electric vehicle (EV) fleet belonging to NYC. We started a project with involvement from undergraduate students through NYU's Vertically Integrated

Projects to develop a tool to assess the steady state access cost for a given location configuration of stations, accounting for congestion costs from queue delay. This is done through a novel **EV access user equilibrium model** and solution method. The tool is available free on our Github site.

Virtual test bed for evaluating travel demand impacts of emerging technologies and policies

Following the development of a synthetic population for NYC, we completed the development of **MATSim-NYC**, a virtual test bed for evaluating citywide travel impacts of new technologies or policies. We published a paper that covers the calibration and validation process of this model as well as evaluating 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. Several applications of the MATSim model have been studied. One example application of the test bed is Ziyi Ma's work on bus network redesigns using MATSim to quantify the impacts on bus ridership in the presence of ridehail options. Jinkai Zhou completed his surrogate-based service region design algorithm to deploy automated vehicle fleets in NYC. Another is the deployment of the Brooklyn-Queens Connector (BQX).

The MATSim-NYC model has been further applied to **evaluate travel under COVID-19**. In this project led by Ding Wang from Prof. Ozbay's group, we recalibrated the mode choice model of the synthetic population as a result of COVID. We also showed how travel under these conditions with reopening can lead to strained congestion levels due to higher driving mode choice, with an increasing need for micromobility options. This work has led us to a collaboration with Oliver Gao at Cornell/CTECH. We presented the initial work at the Bridging Transportation Researchers conference and will be presenting an update with Cornell at a workshop at TRB in January.

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. With the presence of COVID, we are now looking toward renewed efforts in the area of urban deliveries and underserved populations.

Sincerely,

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BUILT Lab members active in 2020

PhD student researchers

Jinkai Zhou, Yueshuai Brian He, Gyugeun Yoon, Ted Pantelidis, Qi Liu, Jesse Fu, Bingqing Chloe Liu, Srushti Rath, Haggai Davis, III

MS student researchers

Ziyi Ma (Eisenhower Fellow), Mina Lee, Nicolas Gomez Rojas, Shams Sahar (Fulbright Scholar), Mengyun Li

Undergraduate student researchers

Divya Bade (UPenn), Harpreet Kaur (Princeton), Michelle Ren

New Research Products in 2020

Journal publications:

1) **He, B. Y.**, **Chow, J. Y. J.**, 2021. Entropy maximizing gravity model of passenger and mobility fleet origin-destination patterns with partially observed service data. *Transportation Research Record*, in press.
2) **He, B. Y.**, **Zhou, J.**, **Ma, Z.**, Wang, D., Sha, D., **Lee, M.**, **Chow, J. Y. J.**, Ozbay, K. 2021. A validated multi-agent simulation test bed to evaluate congestion pricing policies on population segments by time-of-day in New York City, *Transport Policy* 101, 145-161.
3) **Yoon, G.**, **Dmitriyeva, A.**, **Fay, D.**, **Chow, J. Y. J.**, 2020. Effect of routing constraints on learning in contextual bandit mobility-on-demand destination recommendation systems, *IEEE Transactions on ITS*, in press, doi: 10.1109/TITS.2020.3038675.
4) **He, B. Y.**, **Zhou, J.**, **Ma, Z.**, **Chow, J. Y. J.**, Ozbay, K., 2020. Evaluation of city-scale built environment policies in New York City using an emerging mobility-accessible synthetic population, *Transportation Research Part A* 141, 444-467.
5) Ma, T.Y., **Chow, J. Y. J.**, Klein, S., **Ma, Z.**, 2020. A user-operator assignment game with heterogeneous user groups for empirical evaluation of a microtransit service in Luxembourg. *Transportmetrica A*, in press, doi: 10.1080/23249935.2020.1820625.
6) **Xu, S. J.**, **Xie, Q.**, **Chow, J. Y. J.**, Liu, X., 2020. Empirical validation of network learning with taxi GPS data from Wuhan, China, *IEEE ITS Magazine*, in press, doi: 10.1109/MITS.2020.3037324.
7) **Pantelidis, T.**, **Chow, J.Y.J.**, **Rasulkhani, S.**, 2020. A many-to-many assignment game and stable outcome algorithm to evaluate collaborative Mobility-as-a-Service platforms. *Transportation Research Part B* 140, 79-100.
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. *Transportmetrica B*, in press, doi: 10.1080/21680566.2020.1809549.
9) **Yoon, G.**, **Chow, J. Y. J.**, 2020. Contextual bandit-based sequential transit route design under demand uncertainty. *Transportation Research Record* 2674(5), 613-625.
10) **Yoon, G.**, **Chow, J. Y. J.**, 2020. Unlimited-ride bike-share pass pricing revenue management for casual riders using only public data. *IJTST* 9(2), 159-169.

Conference proceedings:

11) **Rath, S.**, **Yoon, G.**, **Scalise, P.**, **Chow, J.Y.J.** (2021). Advances in fixed route transit, semi-flexible transit, and microtransit toward Mobility-as-a-Service. Proc. 100th Annual Meeting of the TRB, Washington, DC.
12) **Liu, Q.**, Chow, J.Y.J. (2021). A schedule-based transit passenger flow estimator using stop-based count data. Proc. 100th Annual Meeting of the TRB, Washington, DC.
13) **Pantelidis, T.**, **Chow, J.Y.J.**, Cats, O. (2021). Risk pooling contracts for multiple transport operators for large scale network incidents. Proc. 100th Annual Meeting of the TRB, Washington, DC.
14) **He, B.Y.**, **Chow, J.Y.J.** (2021). Entropy maximizing gravity model of passenger and mobility fleet origin-destination patterns with partially observed service data. Proc. 100th Annual Meeting of the TRB, Washington, DC.
15) **Ma, Z.**, **Chow, J.Y.J.** (2021). Transit network design with multi-agent simulation to capture activity-based mode competition. Proc. 100th Annual Meeting of the TRB, Washington, DC.
16) **Zhou, J.**, **Chow, J.Y.J.** (2021). Surrogate-based optimization of activity-based connected subgraph problem for robotic taxi fleet service region design. Proc. 100th Annual Meeting of the TRB, Washington, DC.
17) **Liu, B.**, **Bade, D.**, **Chow, J.Y.J.** (2021). A bike count forecast model with multimodal network connectivity measures. Proc. 100th Annual Meeting of the TRB, Washington, DC.
18) **Liu, B.**, **Chow, J.Y.J.** (2021). A stochastic user equilibrium model and solution method for networks with congestible link capacities. Proc. 100th Annual Meeting of the TRB, Washington, DC.

19) **Fu, Z.**, **Chow, J.Y.J.**, Ma, T.Y. (2021). A model and heuristic for the pickup and delivery problem with dynamic synchronized transfers. Proc. 100th Annual Meeting of the TRB, Washington, DC.
20) **Li, M.**, **Chow, J.Y.J.** (2021). A school bus routing problem with a mixed ride, mixed load, and heterogeneous fleet. Proc. 100th Annual Meeting of the TRB, Washington, DC.
21) **He, B.Y.**, **Zhou, J.**, **Ma, Z.**, Wang, D., Sha, D., **Lee, M.**, **Chow, J.Y.J.**, Ozbay, K. (2021). A validated multi-agent simulation test bed to evaluate congestion pricing policies on population segments by time-of-day in New York City. Proc. 100th Annual Meeting of the TRB, Washington, DC.
22) Ma, T.Y., **Chow, J.Y.J.**, Klein, S., **Ma, Z.** (2020). A stochastic user-operator assignment game for microtransit service evaluation: A case study of Kussbus in Luxembourg. Proc. Forum on Integrated and Sustainable Transportation Systems, doi: 10.1109/FISTS46898.2020.9264887.

Research reports:
23) *Synthesis of real time public transit route deviation operational policies*, PI: J.Y.J. Chow; Sponsor: FTA.
24) *Multi-agent Simulation-based Virtual Test Bed Ecosystem: MATSim-NYC*, PI: J.Y.J. Chow, Co-PI: K. Ozbay; Sponsor: C2SMART.
25) *Evaluation of Bus Redesign Alternatives in Transit Deserts under Ride-Hail Presence*, PI: J.Y.J. Chow; Sponsor: C2SMART.

Dissertations and Theses completed:
26) **Zhou, J.**, 2020. *Autonomous vehicle fleet operations and planning with user activity scheduling constraints*. PhD dissertation, New York University.
27) **He, B.Y.**, 2020. *Urban transportation analysis with operator data sharing considerations*. PhD dissertation, New York University.
28) **Pantelidis, T.P.**, 2020. *Network and mechanism design for collaborative transportation systems*. PhD dissertation, New York University.
29) **Gomez Rojas, N.**, 2020. *An electric vehicle scheduling problem to plan for electric bus fleet conversion*. MS thesis, New York University.
30) **Sahar, S.**, 2020. *Behavioral responses to emergency vehicle warning siren.* MS thesis, New York University.
31) **Li, M.**, 2020. *School bus routing problem with mixed ride, heterogeneous fleet, and mixed load.* MS thesis, New York University.

Working papers:
32) Dong, X., **Chow, J.Y.J.**, Waller, S.T., Rey, D. (2020). A chance-constrained dial-a-ride problem with utility-maximizing demand and multiple pricing structures. https://arxiv.org/abs/2011.08993.
33) Wang, D., **He, B.Y.**, Gao, J., **Chow, J.Y.J.**, Ozbay, K., Iyer, S. (2020). Impact of COVID-19 behavioral inertia on reopening strategies for New York City Transit. https://arxiv.org/abs/2006.13368.

Invited Talks:
34) "Design of cyberphysical autonomous mobility platforms", AVWS3 IPAM 2020: Large Scale Autonomy: Connectivity and Mobility Networks, Los Angeles, CA, Nov 16.
35) "Advances toward Mobility-as-a-Service: from traveler to operator and platform perspectives", UC Irvine ITS Seminar, Irvine, CA, Oct 23.
36) "Impact of COVID-19 behavioral inertia on reopening strategies for New York City Transit", Bridging Transportation Researchers Conference #2, Track 1: COVID-19 Pandemic and Transportation, Aug 20.

Conference Presentations:
37) "Reinforcement learning-based transit operation design: from line planning to operation policy", G. Yoon and J.Y.J. Chow, INFORMS Annual Meeting 2020, Session FB48 – ADP/Reinforcement learning in vehicle routing I, Nov. 13.

Prototypes and data:
38) https://github.com/BUILTNYU/EV_Charging_Station_Access_Equlibrium_Model: code for running an electric vehicle access equilibrium model

39) https://github.com/BUILTNYU/ShoolBusRouting_MixedRide: data and code for creating school bus routes that handle mixed ride, mixed load, and heterogeneous fleet
40) https://github.com/BUILTNYU/Pickup_and_delivery_problem_with_dynamic_synchronized_transfers: code for the pickup and delivery problem with en-route synchronized transfers
41) https://zenodo.org/record/4082007#.X-4FathKguU: data for MATSim-NYC model and corresponding synthetic population
42) https://github.com/BUILTNYU/FTA_TransitSystems: code for the simulator that evaluates fixed route, flexible route, and door-to-door microtransit shown in the FTA report
43) https://zenodo.org/record/3894549#.X-87tdhKguU: code and data for MATSim Brooklyn bus network redesign, including conversion of shapefile to GTFS and algorithm to optimize networkwide bus frequencies
44) https://github.com/BUILTNYU/transit-flow-estimation: code for performing static and schedule-based transit flow estimation