FUTURE URBAN MOBILITY

Research Project in the SMART FM IRG
(October 1, 2019)

1. **Project Title: Imitation Learning with Missing Data**

   MIT Faculty Advisor: Patrick JAILLET
   Mentor: Tien MAI
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   Project Description
   We are interested in imitation learning, i.e., the problem of inferring an expert's optimal policy from demonstrated trajectories. The aim of this project is to develop new algorithms that allow to recover an expert's policy with incomplete data, i.e., some parts of the demonstrated data are missing.

   Goals
   To build a new imitation algorithm being able to work with incomplete demonstrations

   Prerequisites/Skills
   Basic machine learning, Programming skills (Python, Matlab)

   Types of Software Applications
   Not identified

   Individual or Team Project
   1 or 2 students

   Relevant Papers and or URLs
   1) Ho, Jonathan, and Stefano Ermon. "Generative adversarial imitation learning". Advances in neural information processing systems. 2016.

2. **Project Title: Route Choice Modeling through Inverse Reinforcement Learning and Imitation Learning**

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   Project Description
   The problem of analyzing and predicting travelers' route choice behavior in a transportation network is one of the main problems in transportation modeling. The most popular approach is to learn/infer a travelers' utility function using observed travelers' path choices. In this context, route choice modeling can be viewed as an inverse

reinforcement learning (IRL) problem, which aims at learning an expert's reward function through demonstrated trajectories. In the aspect of prediction, route choice modeling can be viewed as an imitation learning problem. Given this observation, the aim of the project is to bring some modern IRL and imitation learning techniques from the machine learning literature, e.g., adversarial IRL/imitation learning, to deal with the problem of route choice modeling. We will be investigating whether advanced machine learning algorithms could help improve the performance of classical route choice models.

Goals
1) To implement and provide some comparisons of some advanced machine learning algorithms and classical route choice models
2) Design new route choice models based on the idea of adversarial imitation learning

Prerequisites/Skills
Basic machine learning, Programming skills (Python, Matlab)

Types of Software Applications
Not identified

Individual or Team Project
1 or 2 students

Relevant Papers and or URLs
1) Ho, J., and Ermon, S. 2016. *Generative adversarial imitation learning*. In Advances in Neural Information Processing Systems, 4565–4573.
2) Fosgerau, M.; Frejinger, E.; and Karlstrom, A. 2013. *A link based network route choice model with unrestricted choice set*. Transportation Research Part B 56:70–80.

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3. **Project Title: Structured Non-Parametric Choice Modeling**

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Project Description
In this project, we are interested in non-parametric models that can be used to model and predict the probabilities of selecting items from a discrete set of items. Such models have received a growing attention recently due to their flexibility. We will consider the rank-based model, which is basically represented by a distribution over all the item preferences. We aim at developing a more advanced version by taking into consideration some item information such as item categories, colors, to build a structural rank-based model.

Goals
Build a simple structured rank-based model, develop an efficient estimation method, and evaluate the performance of the new model using some small datasets.

Prerequisites/Skills
Basic Math, Programming skills (Python, Matlab)

Types of Software Applications
Not identified

Individual or Team Project
1 or 2 students

Relevant Papers and or URLs
1) Farias, Vivek F., Srikanth Jagabathula, and Devavrat Shah. "A nonparametric approach to modeling choice with limited data". *Management science* 59.2 (2013): 305-322.

4. **Project Title: Algorithms for Location Planning under General Choice Models**

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Project Description
We will be investigating the problem of how to locate new facilities in a competitive market such that the captured demand of users is maximized, assuming that each individual chooses among all available facilities according to a probabilistic model (i.e., discrete choice model). In this project, we will consider the planning problem under general discrete choice models, including the multivariate extreme value (MEV) and mixed multinomial logit (MMNL) models. These demand models are flexible in capturing customers' behavior, but the resulting optimization problems are challenging as the corresponding objective functions are highly nonlinear and non-convex. To deal with this issue, we will explore some heuristic approaches that allow to practically solve these problems.

Goals
To design an algorithm that outperforms general-purpose solvers

Prerequisites/Skills
Basic Math, Algorithm Design, Linear Optimization, Programming skills (Python, Matlab)

Types of Software Applications
Not identified

Individual or Team Project
1 or 2 students

Relevant Papers and or URLs
1) Ben-Akiva, M. and Lerman, S. R. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, Massachusetts, 1985.
2) Benati, S. and Hansen, P. *The maximum capture problem with random utilities: Problem formulation and algorithms*. European Journal of Operational Research, 43(3):518–530, 2002.

5. **Project Title: Improving Model Selection of Discrete Choice using Bayesian Optimization**

MIT Faculty Advisor: Patrick JAILLET
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Project Description
Discrete choice modeling is widely used to model and predict human's behavior over the decades. There are several discrete choice models that have been proposed in the econometrics and transportation science literatures, making the section of "good models" in some contexts difficult. In this project, we will bring some ideas from machine learning to support the model selection. More precisely, we will focus on a class of multivariate extreme value (MEV) models, which are typically represented by a tree structure with some parameters. The idea here is to select "good" tree structures and parameters by means of Bayesian reasoning, i.e., Bayesian optimization.

Goals
To design an algorithm that allows to find "good" MEV models in terms of predicting people's behavior using a real-world dataset

Prerequisites/Skills
Basic machine learning, Programming skills (Python, Matlab)

Types of Software Applications
Not identified

Individual or Team Project
1 or 2 students

Relevant Papers and or URLs
1) Ben-Akiva, M. and Lerman, S. R. *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, Massachusetts, 1985.
2) Frazier, Peter I. *A tutorial on Bayesian optimization*. arXiv preprint arXiv:1807.02811 (2018).

6. Project Title: SimMobility Freight - Freight Friendly Policies

MIT Faculty Advisor: Moshe BEN-AKIVA
Mentor: Andre ROMANO ALHO
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Project Description

Logistics and goods movement are essential parts of our economy and communities. Growth in commodity and freight vehicle movements is expected for the next decades, particularly due to the increased relevance of e-commerce. However, there are concerns over the externalities generated by freight vehicles (pollution, congestion due to poor parking practices, inefficient operations, etc.) and several policy and regulatory measures are often times put forward as potential solutions. Simultaneously, changes in the freight distribution system are taking place, with new modes and services being deployed. Lastly, being a complex system with conflicting interests between agents (buyers, receivers, shippers, carriers, etc.), adds to the challenge of evaluating impacts of system changes at a broad and specific level.

In SMART FM, we have been developing SimMobility Freight, a multi-scale agent-based simulation platform that can be used to evaluate policy and "what-if" scenarios. With a working prototype, we have been applying the platform to real-world policy cases. We aim to generate insights to contribute towards an understanding better on how changes to the status quo result in changes across the freight distribution systems and on their interactions with passenger travel. Ultimately these insights will allow for freight friendly policies, in the sense of being appealing to freight parties as well as to the community and the environment.

Goals

1) Become familiar with agent-based models and their role in making policy evaluations
2) Configure and apply SimMobility Freight models to "what-if" scenarios as per requirements at time of internship
3) Critically analyse model outputs, generate reports and insights
4) Propose follow up research tracks
5) Present findings to an audience of fellow researchers

Prerequisites/Skills

Agent-based simulation, data/statistical analysis, (light) programming/scripting knowledge (e.g. Python)

Types of Software Applications

SimMobility, R, Python

Individual or Team Project

Suitable for both

Relevant Papers and or URLs
1) https://its.mit.edu/simmobility-freight

7. Project Title: SimMobility Passenger - Autonomous Mobility-on-Demand

MIT Faculty Advisor: Moshe BEN-AKIVA
Mentor: Simon OH
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Project Description
Today, new business model introduced by transportation networking companies have changed the way we view the urban mobility system. Technology and business trends involving big data, machine learning, electrification, connectivity, and autonomy are set to bring additional opportunities to increase accessibility and mobility in urban areas. Particularly, in Singapore, the Autonomous Mobility-on-Demand (AMOD) system emerges as one of the promising alternatives which has enormous potentials and is rapidly embracing new business models on the shared mobility, on-demand ride-hailing, seamless multimodality. Moreover, municipalities are looking for ways to include the autonomous mobility services within public transport to overcome the land-scarce urban environment where the desire for car-ownership has to be balanced against traffic congestion and overall journey time. The initial effort on implementing the autonomous mobility solution predates to the creation of the Committee on Autonomous Road Transport for Singapore (CARTS, 2014) that aims to provide guidance on the research development and deployment of autonomous mobility for Singapore.

Making the AMOD solution as an integrated part of the mobility system is known to reduce inequality, especially when increasing accessibility of travelers to public transit and impacting car-ownership behavior. Yet, for a successful integration, it is crucial to properly understand the implication of this new mobility service under the Singapore context for both demand and supply. To this aim, SimMobility was developed by SMART FM to simulate the effects of a portfolio of technology, policy and investment options under alternative future scenarios. It features (1) detailed interactions between the agents of demand (travelers) and supply (facility and the transportation operations) and (2) multiscale evaluations in time and space, comprising three primary modules (Short-term, Mid-term, and Long-term) in which we consider different decision-making levels of an urban system.

Goals
1) Design and formulation of AMOD service (i.e. routing and matching) within given operational constraints
2) Implementation and testing of the formulated AMOD solutions
3) Simulation study with SimMobility over different service and policy configurations
4) Turn simulation output into scientific knowledge

Prerequisites/Skills
Graph theory, Optimization techniques, Programming language (e.g. Python, R, Matlab),
Data/statistical analysis

Types of Software Applications
SimMobility, R, Python

Individual or Team Project
Suitable for both

Relevant Papers and or URLs
1) https://its.mit.edu/research/simmobility_v1

8. **Project Title: Using Genetic Algorithms to Solve the Path Upgrade Problem for Autonomous Scooters**

MIT Faculty Advisor: Carlo RATTI and Paolo SANTI
Mentor: Daniel KONDOR
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Project Description
With the increased popularity of personal mobility devices (PMDs) and bicycles, either private or shared, there is a growing concern about the increased potential for conflicts with pedestrians. While some cities, especially in developed countries have extensive cycle networks, Singapore lags behind in this respect, despite plans for expansion of cycle infrastructure in the coming decade. While providing proper infrastructure is a challenge, the current situation also presents an opportunity to design paths in a new way, anticipating use by small autonomous vehicles/PMDs. Specifically, in this work, we propose to look at one important aspect of these questions, namely how to identify an optimal set of paths to upgrade for use by a shared self-repositioning personal mobility devices (SRSPMDs), given a limited budget for such upgrades. SRSPMDs are vehicles that can reposition themselves without user intervention, but require their user to drive them. They are expected to enter service in the coming years (e.g. https://scootbee.com). The self-repositioning capability could solve the main problem of current bike-sharing and scooter sharing systems, i.e. low utilization rates and the need of costly rebalancing of the fleet. To provide benefit, SRSPMDs will need upgraded path infrastructure so that conflicts with pedestrians can be avoided.

Goals
In this proposal, we are focusing on a system where SRSPMDs can only use such dedicated infrastructure; our goal is to identify an optimal set of path segments where to build such infrastructure such that a maximum number of trips can be served given a fixed budget for such upgrades. The main motivation for this is that the usage of path segments is uneven; this way, we expect that including path segments that are shared by many trips

will result in better solutions. We start with a set of trips currently made by cyclists or scooters (from a real-world data collection). Our goal is to identify a set of path segments to upgrade in a way that the maximum number of trips are served using only upgraded paths. This way, we are aiming to solve a combinatorial optimization problem.

While it is not feasible to find an exact optimum, a good approximation could be found with genetic algorithms. Here, "genes" can represent path segments or trips in a solution as binary variables and for each combination we can calculate the costs and benefits. Starting from a randomly initialized population of solutions, we perform repeated iterations of random recombination and selection according to "fitness" (defined as benefit /cost ratio, or as the total benefit realized with a constraint on cost). We are hoping to arrive at solutions with successively higher fitness value. As a comparison, we can compare solutions from the genetic algorithm with different heuristics.

Prerequisites/Skills
Experience in programming or simulation and data analytics. Experience with genetic algorithms is a plus, but not strictly required. Experience with other machine learning is helpful as well.

Types of Software Applications
Flexible, Python, C/C++, Matlab, etc.

Individual or Team Project
Both; a motivated individual will be able to have interesting results, but there is enough work for a team of 2-3 students.

Relevant Papers and or URLs
1) https://arxiv.org/abs/1909.03679 (context)
2) https://www.microsoft.com/en-us/research/wp-content/uploads/2017/06/main.pdf (previous, related research)
3) https://en.wikipedia.org/wiki/Genetic_algorithm (overview of genetic algorithms)

9. **Project Title: Predictive Fleet Rebalancing for Autonomous Scooters**

MIT Faculty Advisor: Carlo RATTI and Paolo SANTI
Mentor: Daniel KONDOR
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Project Description
Shared bicycles and scooters proved a popular form of transportation for short trips. This is not without controversy however: a clutter of unused vehicles presents an annoyance to people, while low vehicle utilization can hinder the financial sustainability of such operations. Scooters with self-relocation capabilities were recently proposed and actively researched as a potential solution (e.g. https://scootbee.com). While our recent research

shows that such vehicles have a large potential in achieving higher utilization, real-world operation will highly depend on the available infrastructure and relocation strategy used by the operator. In this project, we propose to investigate how a rebalancing strategy based on short-term estimations and prediction of demand can help making vehicles available where they are most needed.

Goals
This project will use real-world data of shared bicycle or scooter usage as an estimation of demand. First, a baseline scenario will be evaluated where the operator does not have any predictions or expectations of future demand (thus serving trip requests is limited by the availability of nearby vehicles). This will then be compared with multiple possible relocation strategies. Some examples are as follows: 1) Ensure that the distribution of vehicles is as homogeneous as possible; 2) Estimate average demand by location and position vehicles following it; 3) Estimate average demand by location and time of day as well, and use this as a guide in positioning vehicles; 4) Train predictive models which estimate short-term demand. Potentially, a comparison with relocation strategies in bike-sharing systems is possible.

Prerequisites/Skills
Experience in programming and simulations or operations research (e.g. linear programming). Any experience in data analytics and machine learning is beneficial.

Types of Software Applications
Flexible, e.g. Python, C/C++, Matlab or other language / environment could be used.

Individual or Team Project
Both; one person can make progress, while there are lot of directions to explore for a team of 2-3 students.

Relevant Papers and or URLs
1) https://arxiv.org/abs/1909.03679 (context, first results)
2) https://ink.library.smu.edu.sg/cgi/viewcontent.cgi?article=4690&context=sis_research (related research)

10. **Project Title: Visualization of Mass Rapid Transit (MRT) Network Disruptions in Singapore**

MIT Faculty Advisor: Carlo RATTI
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Project Description
Rail network, also called Mass Rapid Transit (MRT) network has been the backbone of every public transportation. However, disruption of MRT is inevitable. Previously, we

studied the disruption management of MRT by developing an optimization model to identify the best bus bridging plan in response to a MRT disruption, so that the negative effects of a disruption could have been minimized. In particular, we considered cases where multiple types of vehicles were available for bridging services. We aimed to reduce the travel delay of commuters and increase the number of commuters that can be served. One case that studies a hypothetical disruption in the central business district area of Singapore was presented to demonstrate our proposed model. In this project, we will focus on developing a visualization environment which we will present results of our optimization model.

Goals
Due to recent technical developments, urban systems generate large and complex data sets. While visualizations have been used to make these accessible, often they are tailored to one specific group of users, typically the public or expert users. The main goal of this project is to present results of our optimization model in such a way that they are understandable to different groups of people. By connecting outputs of previously developed optimization model and visualization interface, we will ensure a better planning for bridging plan once when MRT disruption happens.

Prerequisites/Skills
Experience in web design and services

Types of Software Applications
Flexible, e.g. Python, web design tools, JSON, XML, SOAP

Individual or Team Project
Both; one person can make progress, while there are lot of directions to explore for a team of 2-3 students.

Relevant Papers and or URLs
1) http://senseable.mit.edu/papers/pdf/20190627_Luo-etal_DataDriven_Springer-chapter.pdf

11. **Project Title:** See Projects Below

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Project Description
We are witnessing revolutionary and exciting changes in the mobility landscape involving infrastructure, technology, and policy. Of particular relevance are emerging modes like autonomous vehicles (AVs) and micro-mobility (like e-scooters), and services like mobility-on-demand (Uber, Lyft, etc.). While their impact on transportation infrastructure and use

has received significant attention, we are more interested in understanding how these technologies will shape (or, rather, re-shape) our cities.

This particular project is based on our in-house land use-transport interaction (LUTI) simulator named SimMobility, which has three different components. We will focus specifically on the Long-Term (LT) component that models residential location choice, vehicle ownership choice, and job location choice at the individual and household level.

We are looking for three SMURFs for the following projects:

(1) Automated calibration of LUTI models: Building such a complex simulation tool at a disaggregate level requires several behavioral assumptions. This SMURF will assist the LT team in testing the validity of these assumptions, and proposing a methodology for optimal parameter tuning.

(2) Synthetic population generation: How can we create a synthetic population comprising ~4 million households and ~6 million individuals from a 1% sample collected using a traditional survey? This SMURF will assist the LT team in building on the current method being used, and testing their approach against state-of-the-art methods using machine learning.

(3) Incorporating matrix algebra in LUTI models: Popular data science libraries in the computation and big data realms, e.g. numpy, scikit-learn, TensorFlow, utilize matrix algebra formulations that improve computational efficiency. This SMURF will assist the software programmers in the LT team to implement matrix algebra-based model computations, and evaluate the performance against the current implementation.

Goals
1) Integrating technology and modern statistics into meaningful urban research projects
2) Learning how to work with microsimulations and big data
3) Learning to analyze and visualize spatiotemporal data
4) Learning to working in a large team with members from different research backgrounds

Prerequisites/Skills
1) Interest in transportation, urban planning and policy
2) Familiarity with statistical analysis (linear regression, hypothesis testing)
3) Experience with programming (R or Python for the first two projects, C++ for the third project)

Types of Software Applications
SimMobility is an in-house simulation tool written in C++. We write our own scripts for data analysis and computation using R or Python. If spatial data needs to be visualized, we prefer using QGIS and PostgreSQL, which are open-source tools.

Individual or Team Project

The SMURFs would be working with members of the SimMobility Long-Term team headed by Prof Ferreira, and would be mentored directly by Rounaq Basu.

Relevant Papers and or URLs

1) https://www.jtlu.org/index.php/jtlu/article/view/1186