Robust Electric Vehicle Balancing for Autonomous Mobility-on-Demand Systems

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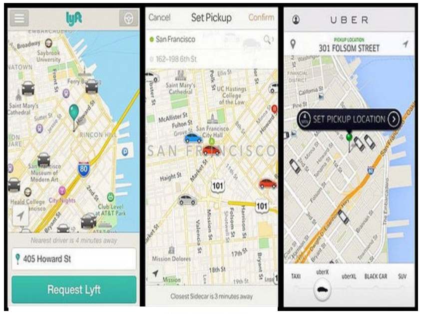
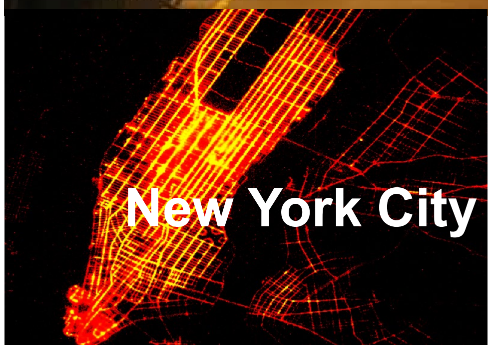
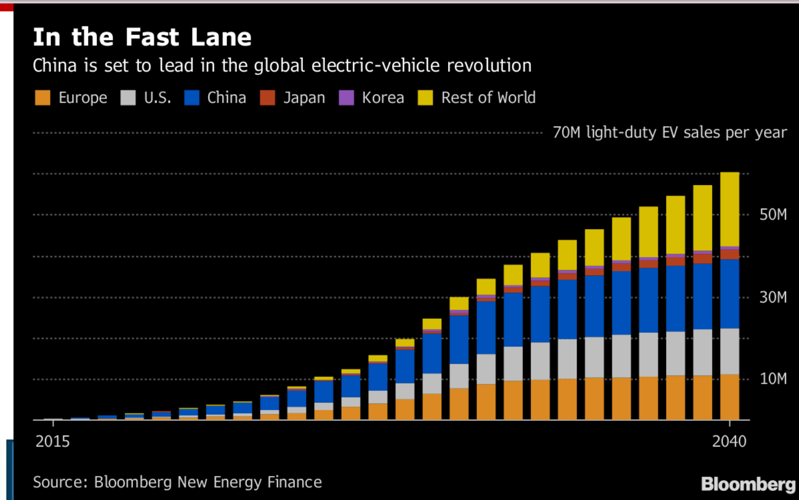
Challenges: Unbalanced, Inefficient Mobility Services





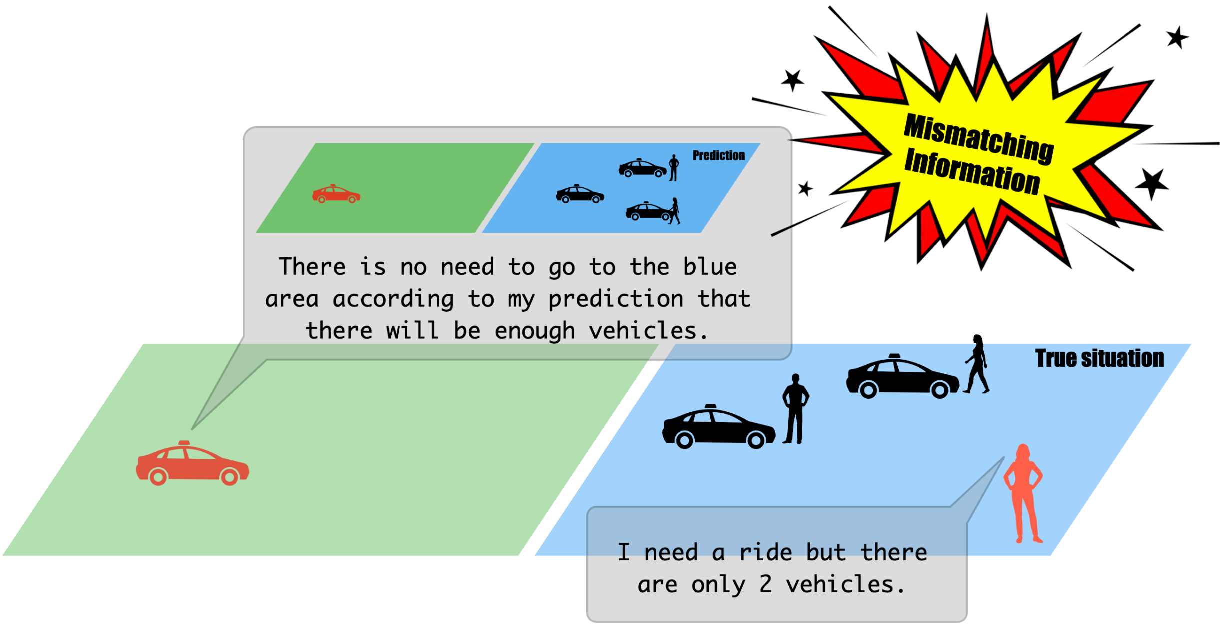
Taxis idle: 300 million miles/year
$200 million waste



Example: Autonomous Mobility-on-Demand (AMoD) Systems

- Literature: assume known or accurate prediction of demand distribution
- EVs’ unique dynamic charging process, hard to predict and schedule

Why Model Uncertainties Matter



Example: demand model uncertainty： vehicle balance or dispatch towards wrong demand information

Contributions and Novelties:

1.Data-Driven Distributionally Robust Optimization (DRO)

Data → predicted demand and supply with **Uncertainty Quantification**

→ **Robust Decision** to improved AMoD fairness and efficiency

2.Robust Multi-agent Reinforcement Learning Methods

DRO EV AMoD under Both Demand and Supply Uncertainties

Demand and charging spots prediction: $r \sim F_r^*, \quad c \sim F_c^*, \quad F_r^* \in \mathcal{F}_r, \quad F_c^* \in \mathcal{F}_c$

EV balance for mobility and charging: $X^{1:\tau} = \{X^1,\ X^2,\ \dots\ X^\tau\}\ \ Y^{1:\tau} = \{Y^1, Y^2, \dots, Y^\tau\}$

EV supply for mobility demand: S_i^k , Low battery EV to charge: T_i^k

$$\min_{X^{1:\tau}, Y^{1:\tau}, S^{1:\tau}, T^{1:\tau}} \max_{\{F_r \in \mathcal{F}_r, F_c \in \mathcal{F}_c\}} \mathbb{E}\left[\sum_{k=1}^{\tau}\left(\underbrace{\boxed{J_D(X^k, Y^k)}}_{\text{Balance cost}} + \beta \underbrace{\boxed{\sum_{i=1}^{n} \frac{c_i^k}{(T_i^k)^\alpha}}}_{\text{Fair charging}}\right)\right]$$

$$\text{s.t.} \quad \underbrace{\boxed{l_i^k S_i^k \le r_i^k \le h_i^k S_i^k}}_{\text{Fair mobility service}}$$

$$S_i^k = f_1(X^{1:k}, c^{1:k}), \quad T_i^k = f_2(Y^{1:k})$$

1.Novelty: Decouple mutual dependency between the EV supply and mobility demand: charging fairness objective, mobility fairness constraint
→decision variables on denominator, not linear or quadratic form opt
2. Theorem: DRO → Equivalent convex optimization, computationally tractable

Sihong He, Fei Miao et.al, IROS 2020; Preprint, IEEE TITS23

Robust and Constrained MARL Method under Model Uncertainties

- Contributions:
- 1. Formulate a robust and constrained MARL problem under state transition kernel uncertainty for EV AMoD systems.
- 2. Minimize the balancing cost while balance the city’s charging and service quality, under model uncertainty.
- 3. Algorithm ROCOMA to train robust policy and develop the first robust natural policy gradient (NPG) to improve the efficiency of policy training.