Joint Optimization of Number of Vehicles, Battery Capacity and Operations of an Electric Autonomous Mobility-on-Demand Fleet

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Introduction

Autonomous
Mobility
On
Demand

“service provided through a joint digital channel that enables users to plan, book, and pay for autonomous mobility services”

- **Ride-haling** companies are gaining momentum
- **Self-driving cars** are becoming a reality
- In the future, **Autonomous Mobility-on-Demand (AMoD)**: self-driving robotaxis

How do we maximize profits?

Right-sizing of the fleet

Minimize purchasing costs of vehicles

- Number
- Range

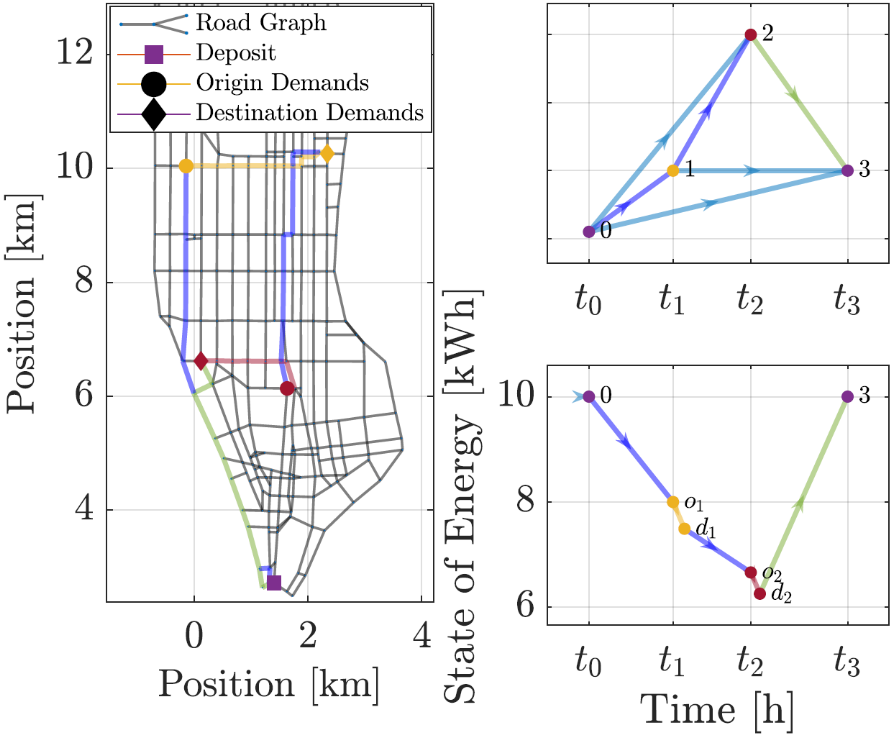
Minimize operational costs of vehicles

- Weight
- Energy consumption

Maximize revenues

- Requests served

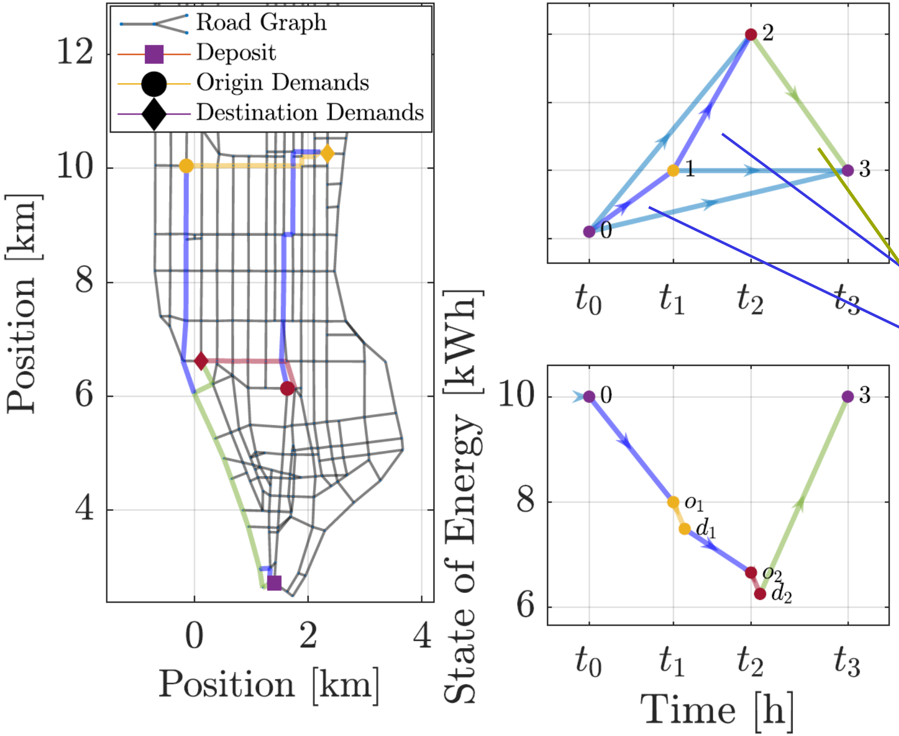
Directed Acyclic Graph (DAG)



DAG representation

- Always follow the fastest path
- Pre-compute all the transitions between travel requests
- Detour to a charging station to charge the vehicle

Directed Acyclic Graph (DAG)



X_{ij}^k 1 if transition between *i* and *j* occurs with vehicle *k*, 0 otherwise

S_{ijc}^k 1 if vehicle *k* goes to charging during transition *i*-*j* using charging station *c*, 0 otherwise

$X_{01}^1, X_{12}^1 = 1$

$X_{23}^1, S_{231}^1 = 1$

Objective Function

$$J = \left(\sum_{k} p_0^k + p_{\mathrm{el}} \sum_{k} \sum_{i,j,c} C_{ijc}^k\right) - \sum_{i} p_i b_{\mathrm{r}}^i$$

Electricity price

Revenue generated by served requests

Energy charged

Vehicle initial cost (amortized) $p_0^k = \frac{\left(p_{\mathrm{v}} b_{\mathrm{v}}^k + p_{\mathrm{b}} E_{\mathrm{b}}^k\right)}{\tau_{\mathrm{v}}}$ [€/day]

Vehicle's consumption $\Delta e^k = \Delta e_0 + \Delta e_{\mathrm{b}} E_{\mathrm{b}}^k$ [kWh/km]

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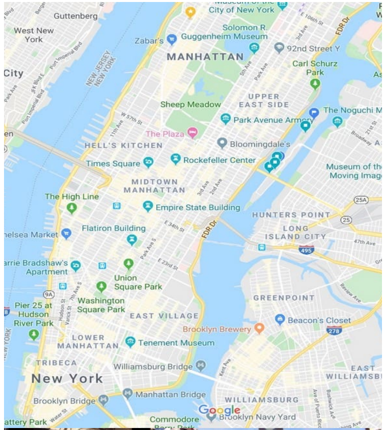
Results: a Case-study of Manhattan



- Manhattan
- Yellow Taxi Cab
- Simulation over 7 days of March 2018
- 2400 requests per day
- Private chargers spread in the area

MILP optimization problem

- Global optimality guarantees
- Commercial solvers
- NP-hard
- Conservative solution

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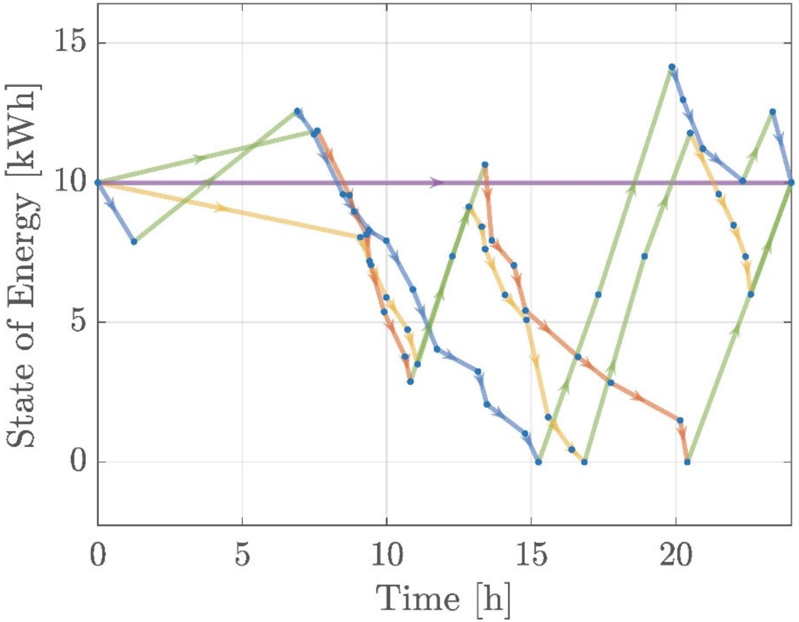
A Small Example



Schedule representation of vehicles:

- 60 requests
- 5 available vehicles (3 used)
- Deterministic solution
- Optimal battery size of 14,12,12 kWh
- Multiple charging trips per day per vehicle
- Does not necessarily charge to 100% SoC

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Manhattan Case-study

Looking for a probability distribution and select a conservative solution

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Inspired by CLT, solving multiple smaller scenarios. The solution of each scenario is used to draw the distribution of the solution of the whole problem

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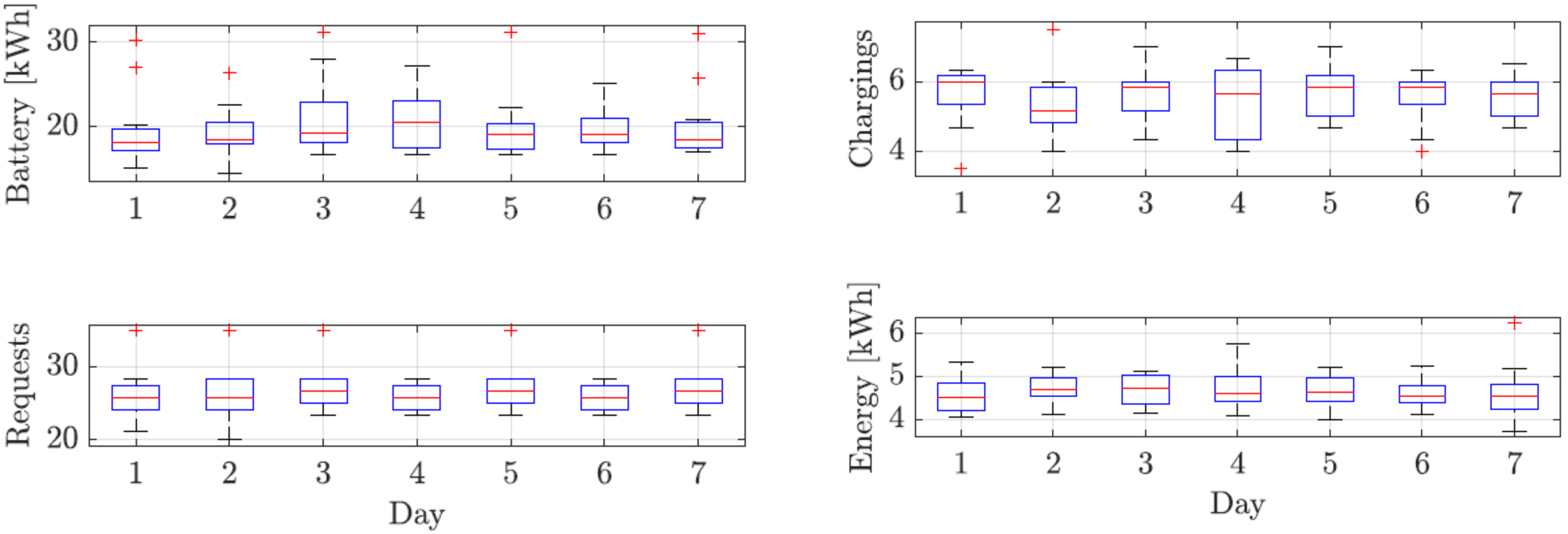
Each day is divided in 12 smaller scenarios

Manhattan Case-study



- Approx. 40 vehicles per 1000 daily requests
- Vehicles of 20 kWh battery
- Charge each vehicle multiple times per day
- Charge only 5 kWh per charging trip

Conclusions & Future Research

- Using a fleet with an optimal battery size (tailored for the specific city) can boost the profit of an AMoD operator
- For Manhattan, using a fleet with 20kWh battery size is enough and can reduce the energy consumption up to 20% compared to a fleet of vehicles with a larger battery size of 45-55 kWh
- Multiple charging per day are required to counter the smaller battery capacity
- Future extension of the model for the optimal siting and sizing of charging stations and ridesharing
- The problem is NP hard: Heuristic solution, Distributed MILP