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# Introduction

## AEVs Produce Mobility Challenges and Opportunities

- AEVs create a new paradigm with capability of driving themselves to charging station after passengers exit
- AEVs in commercial ride-hailing fleets must have the intelligence and awareness to decide when and where to charge, which is a part of an overall fleet management approach



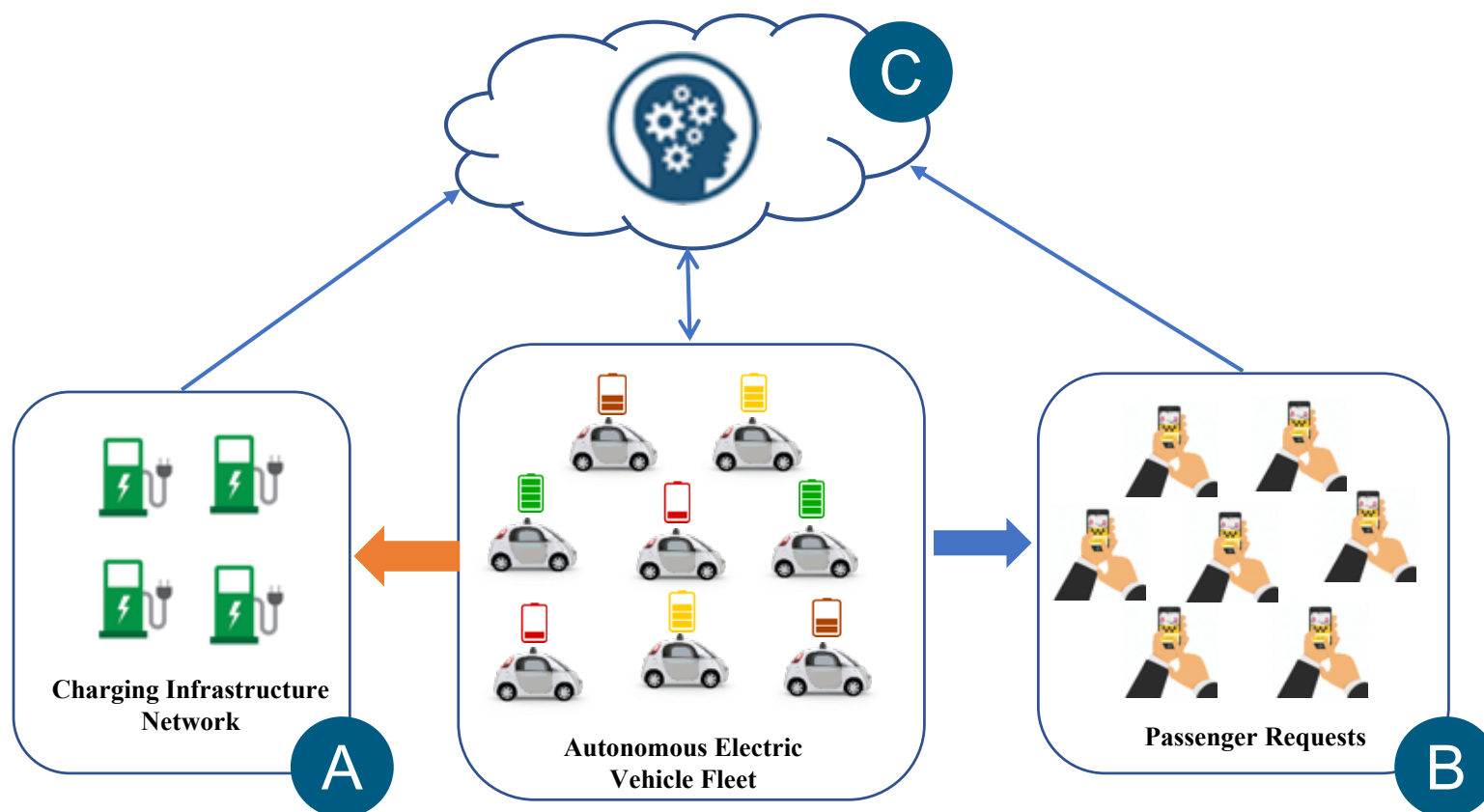
Image Credit: GM Cruise

## Objective

- Develop heuristic and system-optimization approaches for repositioning and charging decisions for an AEV ride-hailing fleet
- Simulate the operation of a fleet of ride-hailing AEVs in New York City (NYC) using the developed approaches
- Quantify and compare the mobility benefits under the two fleet operation strategies

# Approach

## *AEV Ride-Hailing Fleet Operation Framework*

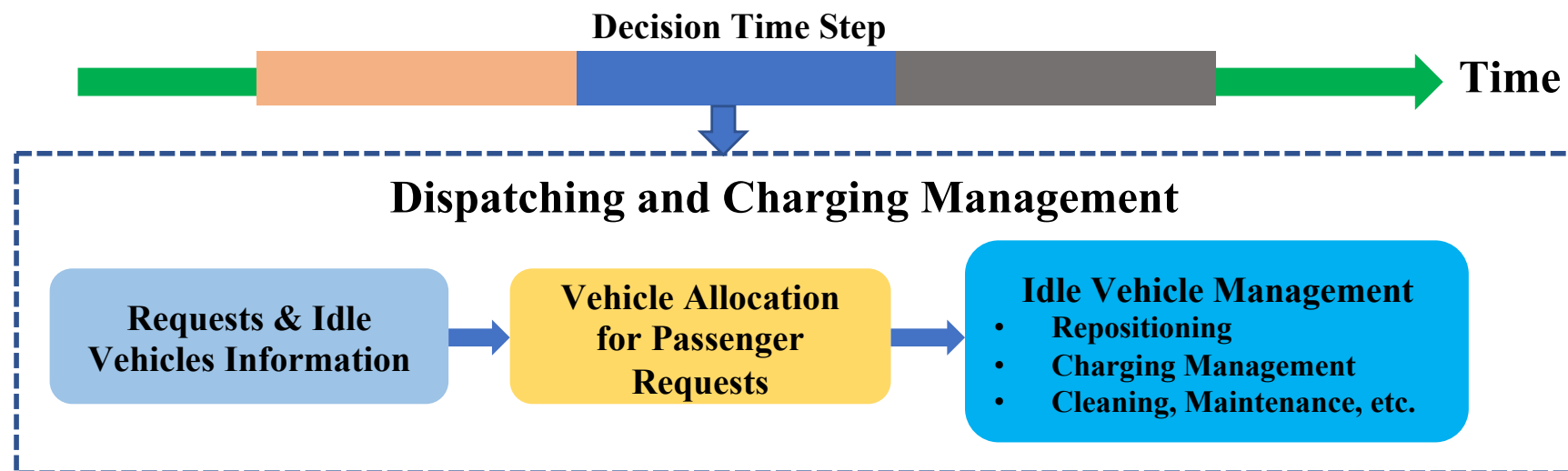


- A. Charging infrastructure network compatible with AEVs
- B. Ride-hailing travel demand (ride requests) represented by pick-up and drop-off location information and rider's maximum wait time
- C. Centralized decision-making framework for dispatching and charging management

# Approach

## *Dispatching and Charging Management*

- **Systematic optimization** approach considers all vehicles, ride requests, and chargers in the area and applies multiple criteria to choose which vehicles to reposition to which areas and whether and where to charge
- **Heuristic** approach assumes each vehicle independently decides whether and where to reposition and charge based on heuristic strategy



# Approach

## *Mechanisms of Two Management Strategies*

### Optimization strategy

Balances the following two competing objectives:

1. Minimize passenger's wait time for pick-up to maximize the number of served requests (not served if wait time > 15 min)
2. Minimize the zero-occupancy vehicle (ZOV) miles driven due to traveling to pick up passengers, repositioning to capture the next ride request, or traveling to charge

### Heuristic strategy

1. A vehicle with sufficient state of charge(SOC) chooses where to reposition by sampling a probability distribution that is weighted toward the area with ride requests with the longest wait time
2. A vehicle chooses the closest unoccupied charging station if SOC drops below threshold

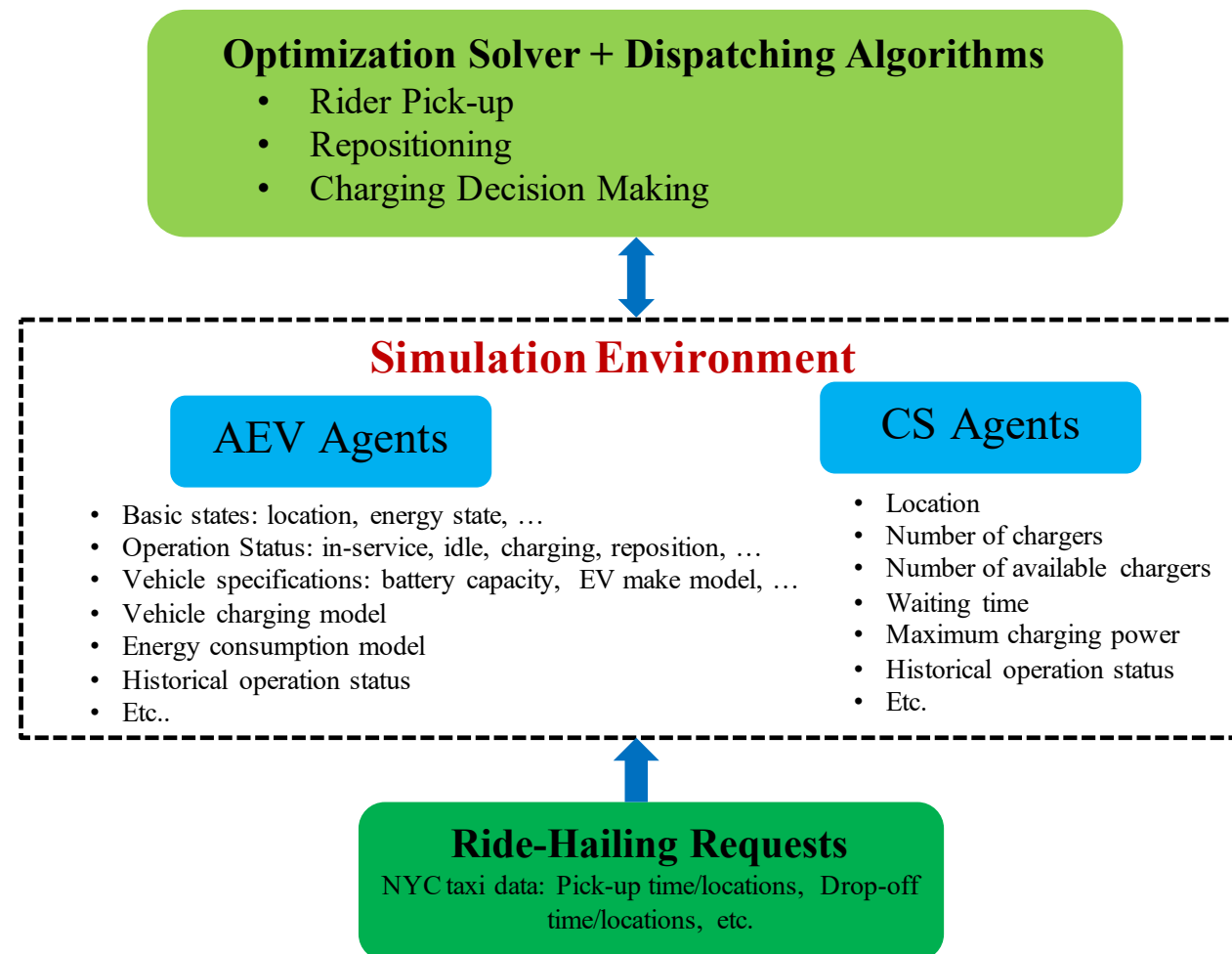
### Performance Metrics

- Zero-occupancy vehicle miles traveled
- Ratio of successfully served ride requests
- Fleet charging downtime
- Utilization rate of charging infrastructure

# Approach

## Agent-based Ride-Hailing Fleet Management Simulation Platform

- Simulation environment includes automated electric vehicle (AEV) agents and charging station(CS) agents.
- Both heuristic and optimization approaches are implemented.
- This platform utilizes real-world ride-hailing requests data to simulate the travel demand from riders, (i.e., New York City taxi data).





# Technical Accomplishments

## Optimization models – Reposition and charging decision making

$$\max \quad \alpha \sum_{v \in V} \sum_{r \in R_v} P_b^{vr} G_v^r + \beta \sum_{v \in V} \left( E_v - \sum_{r \in R_v} P_b^{vr} e_b^{vr} + \sum_{s \in S_v} P_c^{vs} (E_{cp}^v - E_v) \right) - \gamma \sum_{v \in V} \sum_{s \in S_v} P_c^{vs} (t_c^{vs} + \tau_c^{vs})$$

Time cost for charging

Overall reposition rewards

AEV fleet's overall energy state

s. t.

$$\sum_{s \in S_v} P_c^{vs} + \sum_{r \in R_v} P_b^{vr} = 1, \quad v \in V$$

$$\sum_{v \in V} \sum_{r \in R_v} P_b^{vr} = \min(|V|, |R|)$$

$$P_b^{vr}, P_c^{vs} \in \{0,1\}$$

### Input Information

- Idle vehicle status: location/energy state/vehicle specifications
- Charging station status: location/queue wait time/charging power
- Request status: spatial distribution and priority based on wait time

### Decision Output

- Charging decision making
- Repositioning/location selection

$v \in V$ : the set of idle vehicles in the ride-hailing fleet

$r \in R_v$ : the set of TAZs/regions that are close to vehicle  $v$

$s \in S_v$ : the set of charging stations that are close to vehicle  $v$

$P_b^{vr}$ : the decision variable for repositioning

$P_c^{vs}$ : the decision variable for charging

$G_v^r$ : the reward value for vehicle  $v$  repositioning to  $r$

$t_c^{vs}$ : charging time cost for vehicle  $v$  in charging station  $s$

$\tau_c^{vs}$ : travel time cost for vehicle  $v$  to charging station  $s$

$E_v$ : energy state of vehicle  $v$

$E_{cp}^v$ : battery capacity of vehicle  $v$

$e_b^{vr}$ : energy cost for vehicle  $v$  traveling to region  $r$

# Technical Accomplishments

## Optimization models – Charging station selection

$$\min \quad \mu\Delta + \sum_{v \in V} \sum_{c \in C} x_{vc} [(\tau_t^{vc} + \tau_w^c) + (E_{cp}^v - E_r^v)/P_c]$$

Charging time cost

Overall time cost for heading to charge

s. t.

$$\sum_{v \in V} x_{vc} \leq \Delta$$

Total number of vehicles sent to charging station  $c$

$$\sum_{c \in C} x_{vc} = 1$$

$$e_t^{vc} x_{vc} \leq E_r^v$$

$$x_{vc} = \{0,1\}$$

$v \in V$ : the set of vehicles needs to be charged.

$c \in C$ : the set of available charging stations.

$x_{vc}$ : the decision variable

$\tau_t^{vc}$ : the time cost for vehicle  $v$  traveling to charging station  $c$

$\tau_w^c$ : the waiting time for charging at charging station  $c$

$E_{cp}^v$ : the battery capacity of vehicle  $v$

$E_r^v$ : the remaining energy of vehicle  $v$

$e_t^{vc}$ : the energy cost for vehicle  $v$  traveling to charging station  $c$ .

$P_c$ : the maximum charging power at charging station  $c$

### Input Information

- Status of vehicles to be charged: location/energy state/vehicle specifications
- Charging Station Status: location/queue waiting time/charging power

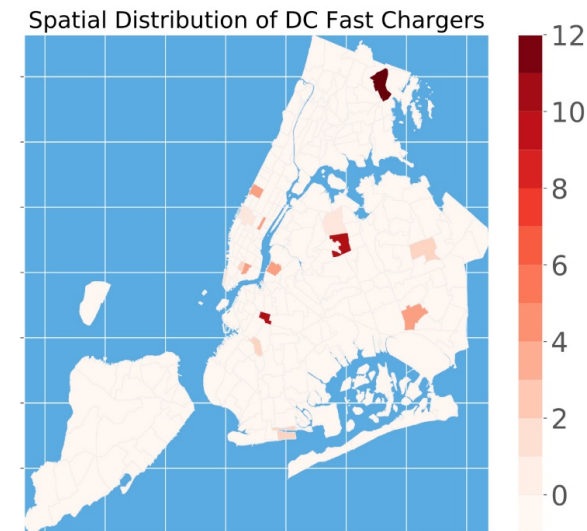
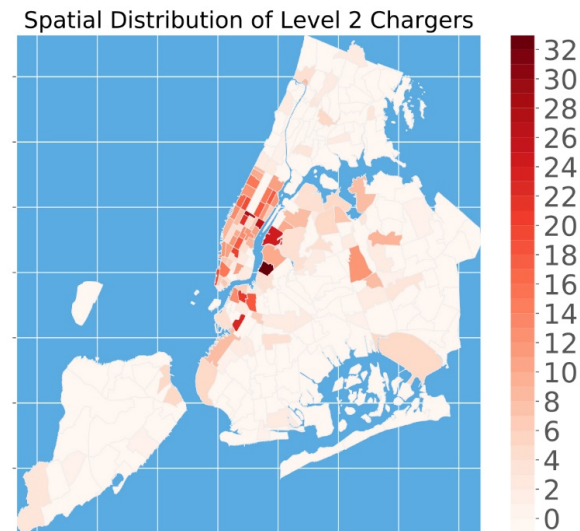
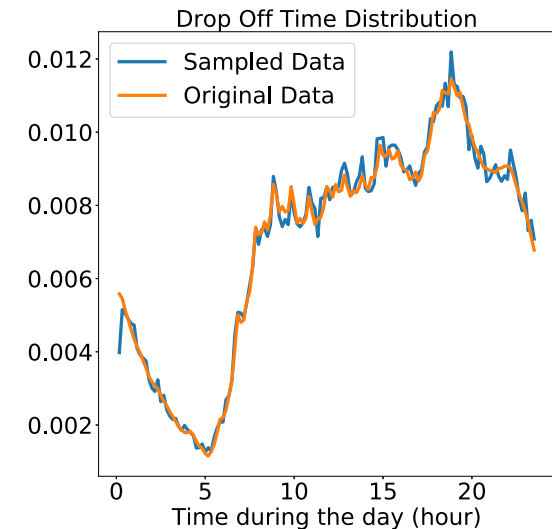
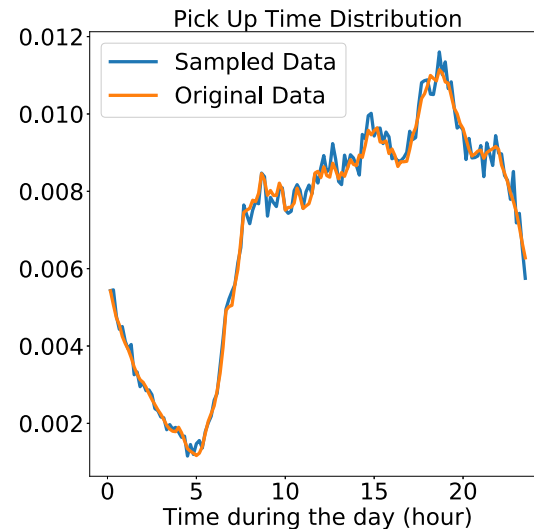
### Decision Output

- Dispatch vehicles to the optimally selected charging station

# Technical Accomplishments

## *Simulation to Demonstrate Fleet Management Strategies*

- 100,000 ride requests each day, sampled from real-world NYC taxi data (approx. 30% of actual daily demand to reduce computation time)
- AEV fleet sizes within the range from 500 to 4,000
- Two options for charging stations:
  1. Today's charging network in NYC with both AC Level 2 and 50-kW DC fast chargers
  2. Use today's charging station locations in NYC, assume all chargers are 50-kW.
- Each run simulated three consecutive days of ride-hailing operation

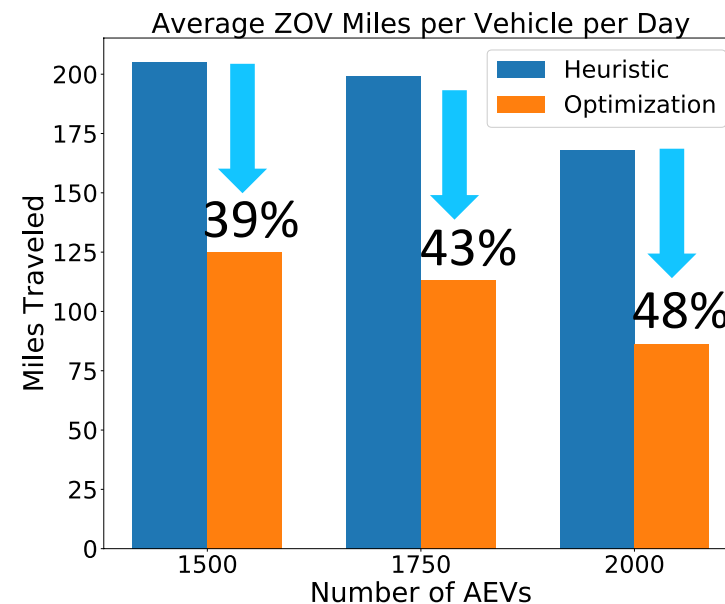
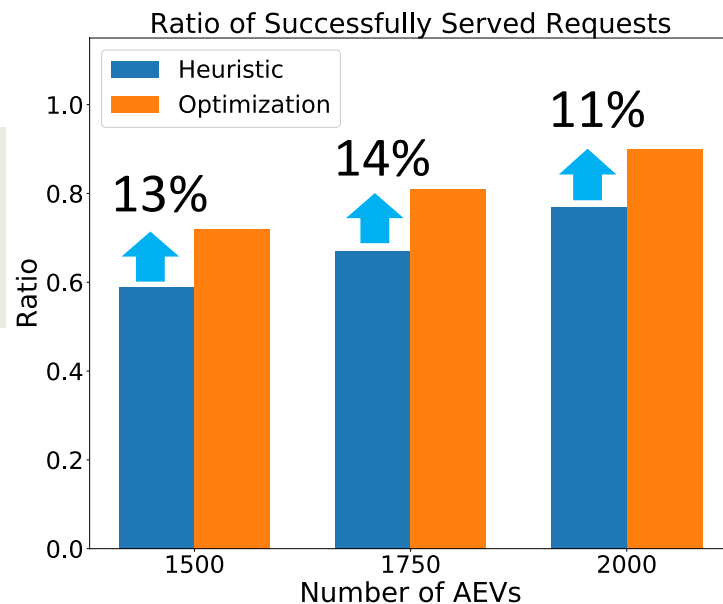


# Technical Accomplishments

## *Benefits of AEV Fleet Operation Using Optimization Approach*

- Optimization is most effective for a fleet size of between 1,500 and 2,000 vehicles
- For a fleet of 1,750 ride-hailing AEVs, optimization-based centralized fleet management would result in 14% more ride requests satisfied and 43% fewer zero-occupancy miles traveled than if AEVs make independent decisions based on heuristic strategy

Using today's charging station locations, assume all chargers are 50-kW



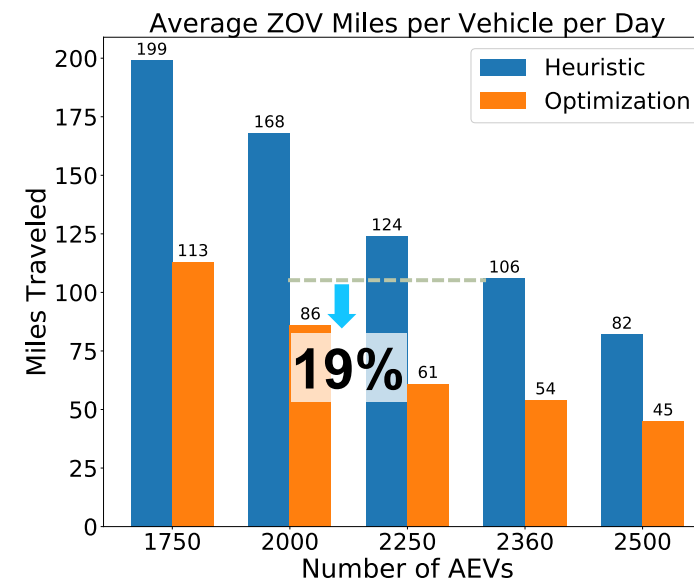
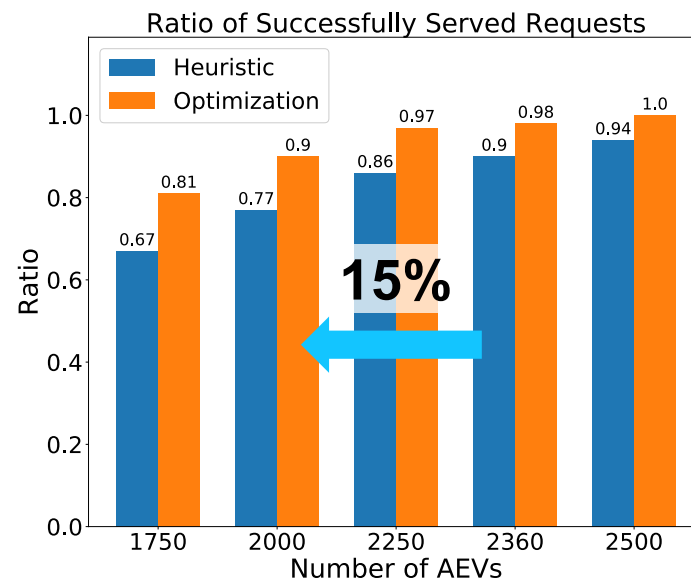
# Technical Accomplishments

## *Benefits of AEV Fleet Operation Using Optimization Approach*

To satisfy 90% of ride requests (i.e. ratio of 0.9):

- An AEV taxi fleet using heuristic strategy needs 2,360 vehicles
- A centrally, optimally controlled fleet needs 2,000 vehicles (15% reduction)
- The smaller, centrally controlled fleet also drives 19% fewer empty miles

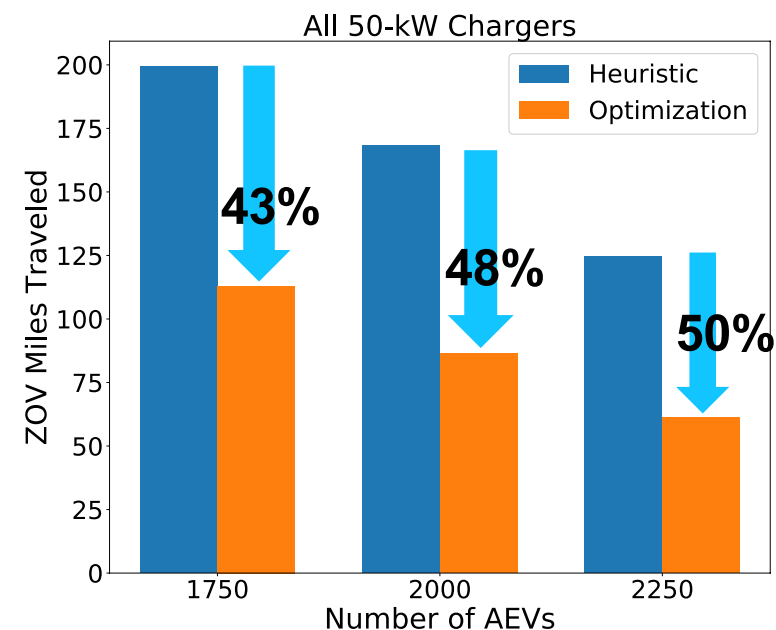
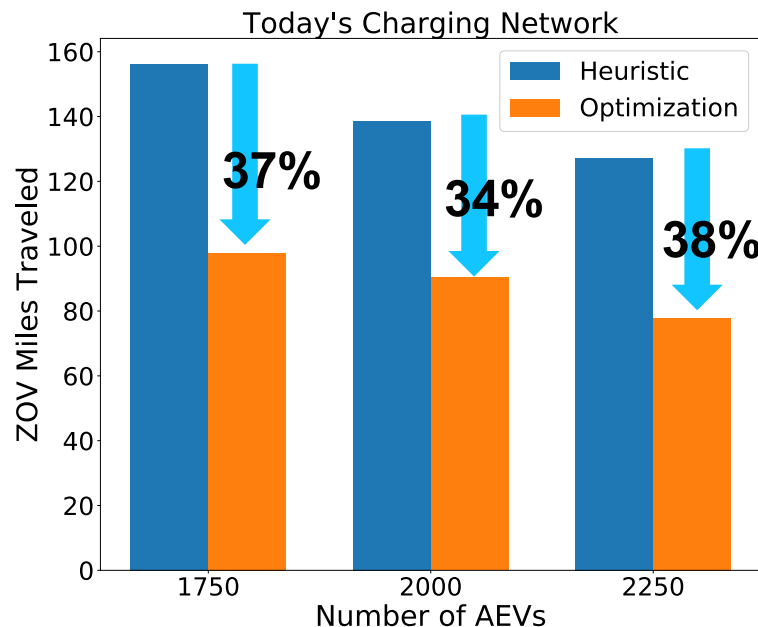
Using today's charging station locations, assume all chargers are 50-kW



# Technical Accomplishments

## *Performance under Different Charging Networks*

- Optimization is more effective when fleet has greater access to fast charging.
- 6% - 14% greater reduction in zero occupancy vehicle miles when all chargers are 50-kW.

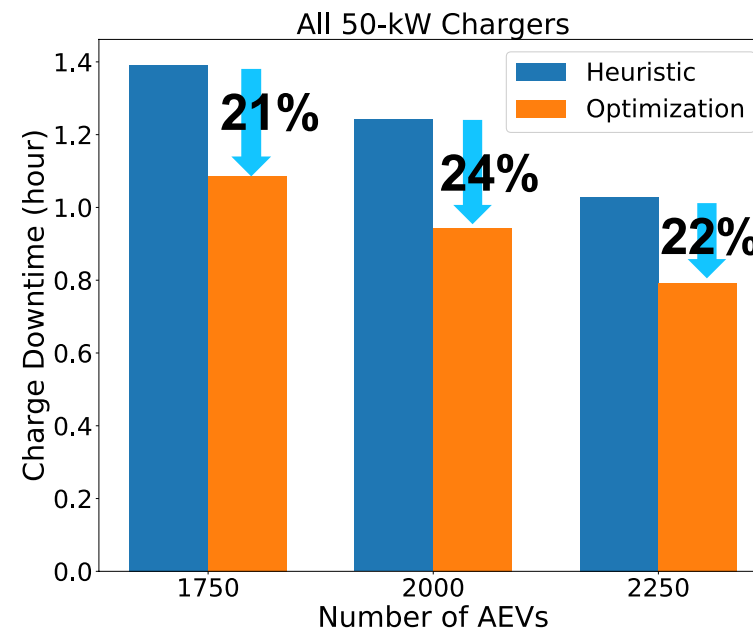
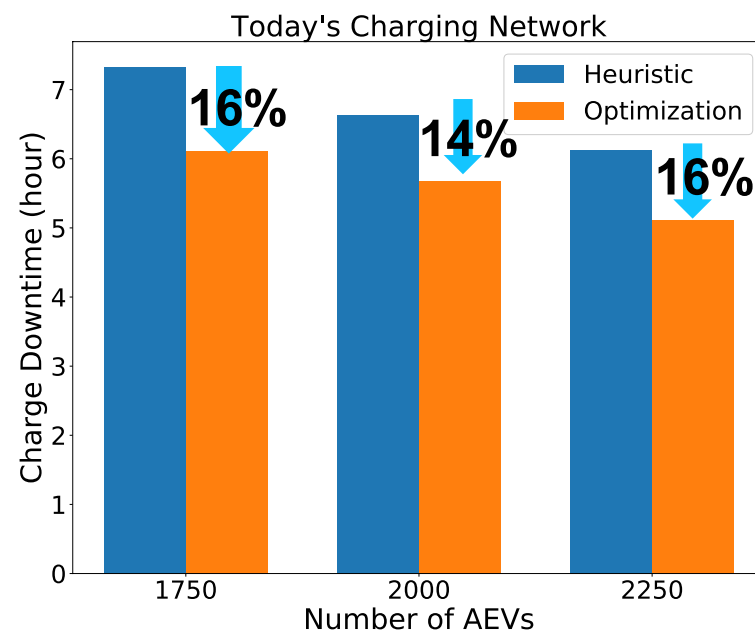




# Technical Accomplishments

## *Performance under Different Charging Networks*

- Optimization approach provides at least 14% greater reduction in charging downtime than heuristic approach
- Centrally optimized fleet can gain additional reduction in charging downtime (at least 5%) when using 50-kW charging network



## Summary

- Developed a framework for integrated dispatching and charging management of an automated electric vehicle ride-hailing fleet
- A case study in New York City was conducted to investigate the benefits of systematic optimization approach comparing to a heuristic approach
- **Key findings:**
  - For a fleet of 1,750 ride-hailing AEVs to meet 100,000 daily requests in NYC, optimization-based, centralized fleet management would result in 14% more ride requests satisfied and 43% fewer zero-occupancy miles traveled than if AEVs make independent decisions based on heuristic strategy
  - Optimization approach can provide considerable reductions in both ZOV miles and charging downtime, and more benefits can be achieved when the fleet has access to faster charging network



## ***Future Research***

The following additional research is recommended for future work to make increasingly intelligent dispatching decisions to improve operational efficiency and increase mobility

- Dynamic intelligent algorithms should be developed that adapt to varying grid, traffic, and other conditions
- Prediction capabilities for transportation system activities will be important to enable sophisticated fleet management strategies
- Multi-stage optimization and artificial intelligence (AI) approaches should be investigated to consider both spatial and temporal dynamics of ride-hailing requests and AEV operations
- Future research should also study how to manage high-mileage electric vehicle driving and charging to maximize vehicle and battery life