Motivation

Carsharing

Potential to reduce demand for vehicle ownership.

Challenge of getting vehicles to users has limited growth.

Autonomous vehicles can remove many of these limitations.

Automatically move to users.
Relocate to high demand areas.

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Minimum Cost Matching for Autonomous Carsharing
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Autonomous Mobility-On-Demand (AMoD) Systems

- Mobility-On-Demand systems provide transportation when a user needs it.
- AMoD systems use autonomous vehicles to improve user experience.
Related Literature

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Taxi Dispatch Problem
- Assign taxis to users calling from different locations.
- Standard objective is to minimize taxi travel time and user wait time.
Problem Description

time →
Problem Description

Car Request

0 1 2 3 4 5 6 7 8

time →
Problem Description

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Notation

Formalized as a sequential bipartite graph matching problem.

- $U_t$ - the set of user agents requesting a ride at time $t$.
- $V_t$ - the set of vehicle agents available at time $t$.
- $(u, v)$ is an assignment of vehicle $v \in V_t$ to user $u \in U_t$.
- $\ell_{uv}$ is the distance from $u$ to $v$. 
Desiderata

Minimum Cost

Find a set of assignments, $M$, such that $|M|$ is maximal and $\sum_{(u,v) \in M} \ell_{uv}$ is minimized.

Minimum Makespan Objective

Find a set of assignments, $M$, such that $|M|$ is maximal and $\max_{(u,v) \in M} \ell_{uv}$ is minimized.

Strategic Manipulability

Find a set of assignments, $M$, such that $|M|$ is maximal and no user agent, $u$, has incentive to misreport their location to decrease $\ell_{uv}$.
Desiderata

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**Strategic Manipulability**

Find a set of assignments, $M$, such that $|M|$ is maximal and no user agent, $u$, has incentive to misreport their location to decrease $\ell_{uv}$. 
Current carsharing systems use a first-come-first-serve assignment strategy:
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We refer to this method as the decentralized approach.
Coordination can improve assignment:

Baseline #2
Baseline #2

Coordination can improve assignment:

We refer to this method as the greedy approach.
The optimal approach is the Hungarian algorithm\(^1\) for minimum cost maximal matching.

The optimal approach is the Hungarian algorithm\textsuperscript{1} for minimum cost maximal matching.

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The Hungarian algorithm is optimal for our first objective.

\textsuperscript{1}Harold W Kuhn. “The Hungarian method for the assignment problem”. In: 
The Hungarian algorithm minimizes total distance at the expense of a subset of users who may experience long wait times.
Minimal-makespan Algorithms

The Hungarian algorithm minimizes total distance at the expense of a subset of users who may experience long wait times.

We minimize makespan with Scalable Collision-avoiding Role Assignment with Minimal Makespan (SCRAM) algorithms\(^2\).

Simulated Empirical Studies

Empirical Analysis

1. Minimum cost objective
2. Minimum makespan objective

Simulated model of carsharing.3.

- Simulate 50 days of carsharing operations in Austin, TX with each algorithm.
- Measure total unoccupied miles travelled.
- Measure wait time for every user.

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Reduction in Distance Traveled

Average Unoccupied Distance Traveled (miles per day)

Decentralized | Greedy | Hungarian | SCRAM

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Reduction in Distance Traveled

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Reduction in Long Wait Times

![Graph showing reduction in long wait times with different algorithms: Decentralized, Greedy, Hungarian, SCRAM. The x-axis represents wait time in minutes (5, 10, 15), and the y-axis represents the number of passengers waiting.]
Reduction in Long Wait Times

![Graph showing reduction in long wait times with four methods: Decentralized, Greedy, Hungarian, and SCRAM. The graph plots the number of passengers waiting against wait times of 5, 10, and 15 minutes. The Decentralized method shows the highest number of passengers waiting at each wait time, followed by Greedy, Hungarian, and SCRAM.]
Strategic Manipulability

- More complex assignment strategies may be suboptimal for individual user agents.
- Introduces a motivation to manipulate the system.

Top user: 5, Bottom user: 7
Strategic Manipulability

- More complex assignment strategies may be suboptimal for individual user agents.
- Introduces a motivation to manipulate the system.

Top user: 6, Bottom user: 6
Strategic Manipulability

- More complex assignment strategies may be suboptimal for individual user agents.
- Introduces a motivation to manipulate the system.

Top user: 7, Bottom user: 5
Strategic Manipulability

- More complex assignment strategies may be suboptimal for individual user agents.
- Introduces a motivation to manipulate the system.

Top user: 7, Bottom user: 1
More complex assignment strategies may be suboptimal for individual user agents.

Introduces a motivation to manipulate the system.

We prove that setting a cancellation fee equal to Vickery-Clarkes-Groves (VCG) payments removes incentive to manipulate the system.
More complex assignment strategies may be suboptimal for individual user agents.

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Top user: 7, Bottom user: 1 8

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Conclusion

Contributions:

1. Analyzed methods for assigning vehicles in a carsharing system.
2. Presented a method that considers makespan of assignment.
3. Demonstrated and provided a solution to the problem of system manipulation.

Future Work:

2. Analyzing makespan and manipulability of taxi-dispatch algorithms.
Questions?