Throughput-Fairness Tradeoffs in Mobility Platforms

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MobiSys 2021
Mobility Platforms

- package delivery
  - UPS
  - FedEx
  - Amazon

- food delivery
  - DoorDash
  - Grubhub
  - Uber Eats

- ridesharing
  - Uber
  - Lyft
Drones-as-a-service

- package delivery
- traffic sensing
- air quality mapping
- aerial photography

shared drone fleet
Mobility Platforms

Customers

Cust. 1
Cust. 2
Cust. 3

delivery orders (tasks)

Vehicles

Uber Eats

Compute Schedule

Vehicle Routing Problem

completed tasks

routes per vehicle
Platform Throughput: Maximize total throughput (task completion rate).

Customer Fairness: Deliver similar per-customer throughputs.
Why fairness?

Did Uber Just Enable Discrimination by Destination?
In California, the ride-hailing company is changing a policy used as a safeguard against driver discrimination against low-income and minority riders.

By David Zipper
December 11, 2019

Uber Help
We're here to help
Driving & Delivering
Describe your Issue

What is destination discrimination?

Per our Community Guidelines, it is unacceptable to discriminate on the basis of a rider's destination.

Repeated instances of canceling trips due to rider's destination can lead to loss of access to Uber apps.

reactive apps require timely measurements
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness

Spatio-temporal diversity of tasks
Mobility makes fairness challenging

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Timescale of fairness

Spatio-temporal diversity of tasks

Max Throughput

<table>
<thead>
<tr>
<th></th>
<th>17 orders</th>
<th>3 orders</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>17 orders</td>
<td>3 orders</td>
<td>20 orders</td>
</tr>
</tbody>
</table>

10 orders

7 orders

3 orders
Mobility makes fairness challenging

- Attributing vehicle time to customer
- Timescale of fairness
- Spatio-temporal diversity of tasks

### Max Throughput
- Total: 20 orders
- 17 orders
- 3 orders

### Round Robin
- Total: 8 orders
- 4 orders
- 4 orders

11 orders: 3 orders
20 orders: 17 orders
4 orders: 4 orders
8 orders: 4 orders
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness

Spatio-temporal diversity of tasks

17 orders

3 orders

20 orders

4 orders

4 orders

8 orders

9 orders

6 orders

15 orders

Max Throughput

Round Robin

Dedicated
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness

Spatio-temporal diversity of tasks

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<table>
<thead>
<tr>
<th>Method</th>
<th>Max Throughput</th>
<th>Round Robin</th>
<th>Dedicated</th>
<th>Mobius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 orders</td>
<td>4 orders</td>
<td>9 orders</td>
<td>10 orders</td>
</tr>
<tr>
<td>Total</td>
<td>20 orders</td>
<td>8 orders</td>
<td>15 orders</td>
<td>19 orders</td>
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∞
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness

Spatio-temporal diversity of tasks

Cannot attribute travel time easily between customers.

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<th>Dedicated</th>
<th>Mobius</th>
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<tr>
<td></td>
<td>16 orders</td>
<td>10 orders</td>
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</tr>
<tr>
<td>Total</td>
<td>20 orders</td>
<td>15 orders</td>
<td>19 orders</td>
</tr>
</tbody>
</table>
Mobius = mobi(lity) + us

An online scheduler that delivers high throughput and fairness.
Problem setup

Customer Tasks

Vehicles
Problem setup

Customer Tasks

Vehicles
• schedule 10-min round trips
• renew all tasks at start of each round trip
Feasible schedules

- schedule 10-min round trips
- renew all tasks at start of each round trip
Feasible schedules

- schedule 10-min round trips
- renew all tasks at start of each round trip
Pareto frontier

- schedule 10-min round trips
- renew all tasks at start of each round trip
Pareto frontier

- schedule 10-min round trips
- renew all tasks at start of each round trip

Pareto Frontier: \{A, B, C, D, E\}
Convex boundary

- schedule 10-min round trips
- renew all tasks at start of each round trip

Pareto Frontier: \{A, B, C, D, E\}

Corner Points: \{A, C, D, E\}
• schedule 10-min round trips
• renew all tasks at start of each round trip

Corner Points: \{A, C, D, E\}
- schedule 10-min round trips
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**Corner Points:** \{A, C, D, E\}
Convex boundary

- schedule 10-min round trips
- renew all tasks at start of each round trip
Convex boundary

- schedule 10-min round trips
- renew all tasks at start of each round trip
Dynamic environments

- schedule 10-min routes
- replan every 3 min
- update tasks every 3 minutes
  (according to spatial distribution in map)
Dynamic environments

- schedule 10-min routes
- replan every 1 min
- update tasks every 3 minutes
  (according to spatial distribution in map)

💡 Vehicles move continuously over space.
💡 Customer tasks observe spatial locality.
Key insights

💡 Feasible set becomes convex with time.
💡 Convex boundary trades off short-term fairness for a boost in throughput.
💡 Target throughput becomes achievable with more time.
Mobius in action

After Round 1

<p>| | | |</p>
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<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>18 orders</td>
<td></td>
</tr>
<tr>
<td></td>
<td>12 orders</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>30 orders</td>
</tr>
</tbody>
</table>

Vehicle 1

Vehicle 2
Mobius in action

<table>
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<th>Vehicle 1</th>
<th>Vehicle 2</th>
</tr>
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</table>

**After Round 1**
- 18 orders
- 12 orders
- Total: 30 orders

**After Round 2**
- 28 orders
- 32 orders
- Total: 60 orders
Mobius in action

After Round 1
18 orders
12 orders
Total 30 orders

After Round 2
28 orders
32 orders
Total 60 orders

After Round 3
49 orders
43 orders
Total 92 orders
More details in paper

• How Mobius efficiently computes corner points on convex boundary
• Extending Mobius to more customers
• Supporting a class of fairness objectives (e.g., proportional fairness)
• Analysis of Mobius’s optimality
Mobius Scheduler

• ~2300 lines of Go
• Plugs with most external VRP solvers
  • Google OR-Tools
  • Gurobi

Customers (Apps)

• Apps can be written in Python, Go, etc.
• App logic can rely on ML models

mobius-scheduler/mobius

mobius-scheduler/apps
Lyft Ridesharing in Manhattan

Setup
- 13-hour trace
- 16k requests
- 40 neighborhoods (zones)
- 200 vehicles

Want to fulfill pickups from all zones equitably (max-min fairness).
Lyft Ridesharing in Manhattan

heatmap colors:
bright $\rightarrow$ $\gg$ tput
homogenous $\rightarrow$ $\gg$ fair

block size:
large $\rightarrow$ $\gg$ tput
equal size $\rightarrow$ $\gg$ fair

Each block = 1 zone

Long-term Throughput (rides/hr)
Lyft Ridesharing in Manhattan

Max Tput
Dedicated Vehicles
Mobius

heatmap colors:
bright → » throughput
homogenous → » fair

block size:
large → » throughput
equal size → » fair

Long-term Throughput (rides/hr)

each block = 1 zone

Max throughput - Dedicated vehicles
Mobius

1 25 50 75 100 150 250

Zone Throughput (rides/hr)
Lyft Ridesharing in Manhattan

heatmap colors:
bright → high throughput
homogenous → fair

block size:
large → high throughput
equal size → fair

Max Tput

Dedicated Vehicles

Mobius

Long-term Throughput (rides/hr)

each block = 1 zone

Mobius

Max throughput-
Dedicated vehicles

Zone Throughput (rides/hr)
Lyft Ridesharing in Manhattan

- Heatmap colors:
  - Bright → Max throughput
  - Homogenous → Fair

- Block size:
  - Large → Max throughput
  - Equal size → Fair

Each block = 1 zone
Lyft Ridesharing in Manhattan

heatmap colors:
- bright → >tput
- homogenous → >fair

block size:
- large → >tput
- equal size → >fair

Long-term Throughput (rides/hr)

Zone Throughput (rides/hr)
Urban Sensing in Boston

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Parking</th>
<th>Air Quality</th>
<th>iPerf</th>
<th>Roof</th>
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</table>

- **Traffic**
  - 5.6 m/s
  - 5.2 m/s
  - 7.2 m/s

- **Parking**
  - 12 parked cars

- **Air Quality**
  - PM 2.5 sensor
  - Measured PM 2.5

- **iPerf**
  - TCP Tput
  - Max Throughput

- **Roof**
  - Mobius (Max−Min)
  - Mobius (Prop. Fair)

### Tasks

- **Continuous Monitoring**
  - 11 tasks (10 sec/task)
  - Prioritizes tasks with high variance in speed

- **Recurring Tasks**
  - 3 tasks (60 sec/task)
  - Tasks renew after 10 mins

- **One-Time Tasks**
  - 50 tasks (20 sec/task)
  - Prioritizes using Gaussian Process model

- **Cyclic Monitoring**
  - 100 tasks (10 sec/task)
  - Renews all tasks after each cycle

### Long-Term Throughput

- **Mobius**
  - Max−Min
  - Prop. Fair
- **Traffic**
- **Parking**
- **Air Quality**
- **iPerf**
- **Roof**

- **Dedicated Drones**

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• Characterized **throughput-fairness tradeoffs** caused by shared mobility

• Discovered that the **convex boundary** strikes the right balance

• Designed **Mobius**, an online scheduler for mobility platform operators

• Showed that Mobius **computes high throughput + fair schedules** and **operates at scale**