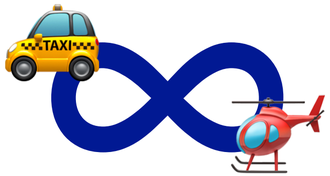
Throughput-Fairness Tradeoffs in Mobility Platforms



Arjun Balasingam, Karthik Gopalakrishnan, Radhika Mittal, Venkat Arun, Ahmed Saeed, Mohammad Alizadeh, Hamsa Balakrishnan, Hari Balakrishnan

MobiSys 2021

CSAIL

Mobility Platforms

package delivery

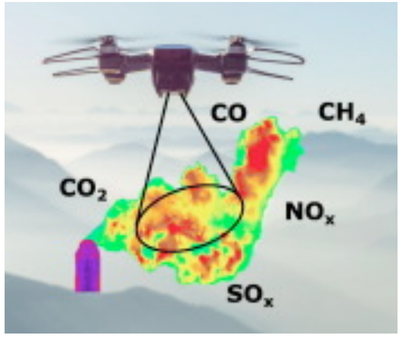
food delivery

ridesharing

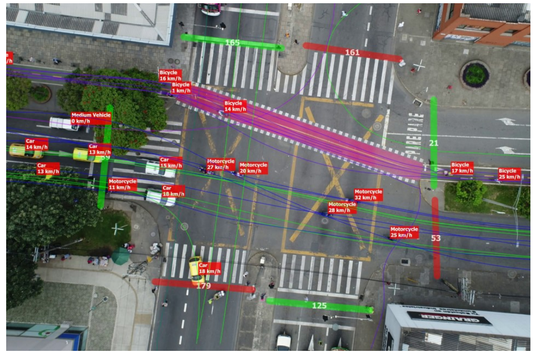
Drones-as-a-service

shared
drone fleet

package delivery



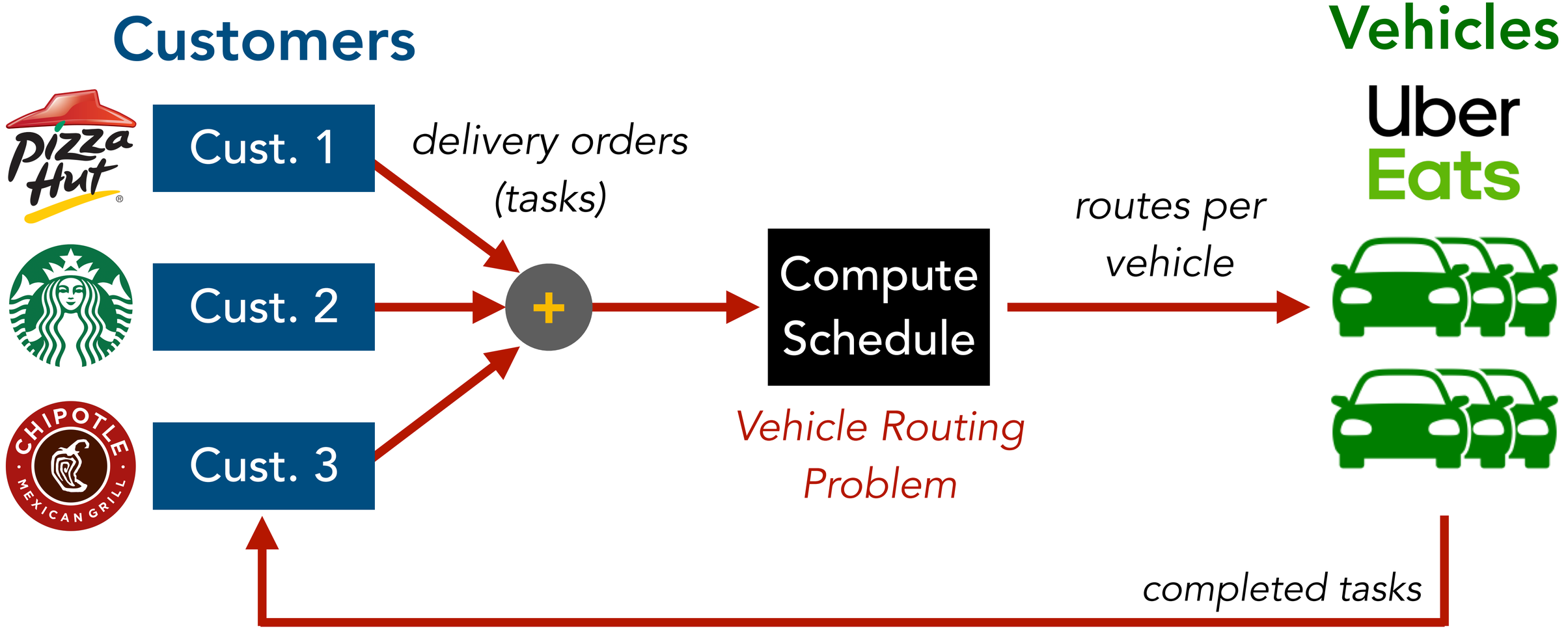
air quality mapping



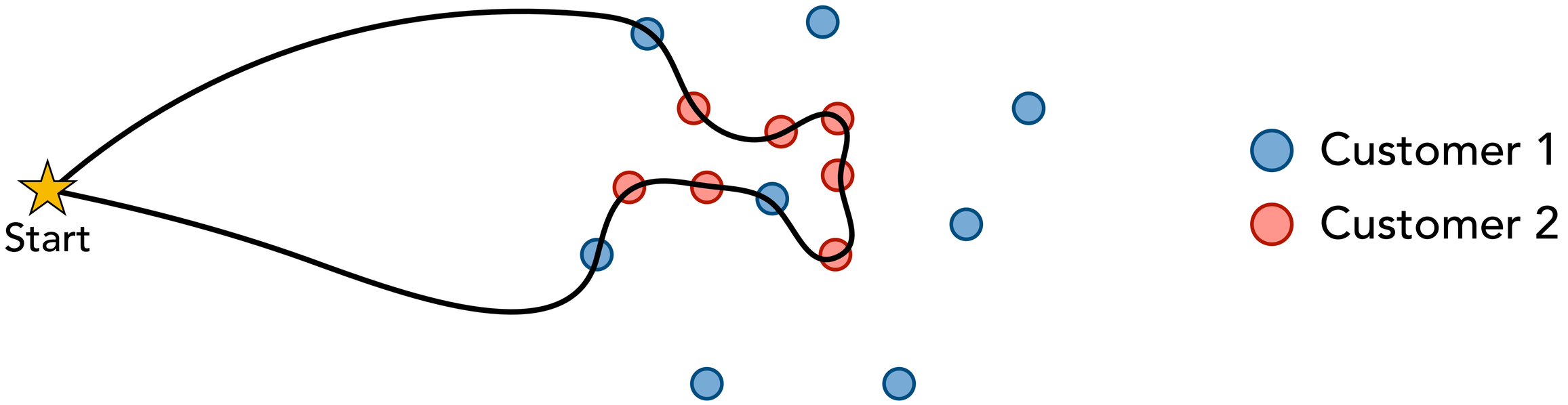
traffic sensing

aerial photography

Mobility Platforms



Vehicle Routing Problem (VRP)



✅ **Platform Throughput:** Maximize total throughput (task completion rate).

💡 **Customer Fairness:** Deliver similar per-customer throughputs.

Why fairness?

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CITYLAB

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

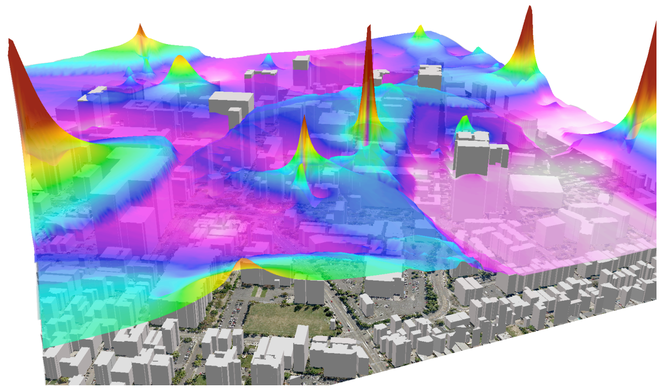
PROP 22 BENEFITS
TRIP ISSUES AND ADJUSTMENTS
USING THE APP
DELIVERING WITH UBER
ACCOUNT AND PAYMENT
SIGNING UP TO DRIVE

DRIVING & DELIVERING > USING THE APP >

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.

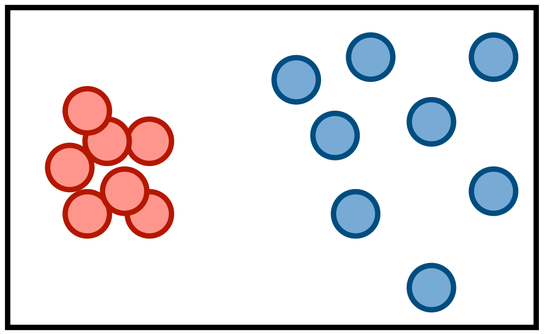


reactive apps require timely measurements

Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness

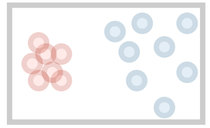


Spatio-temporal diversity of tasks

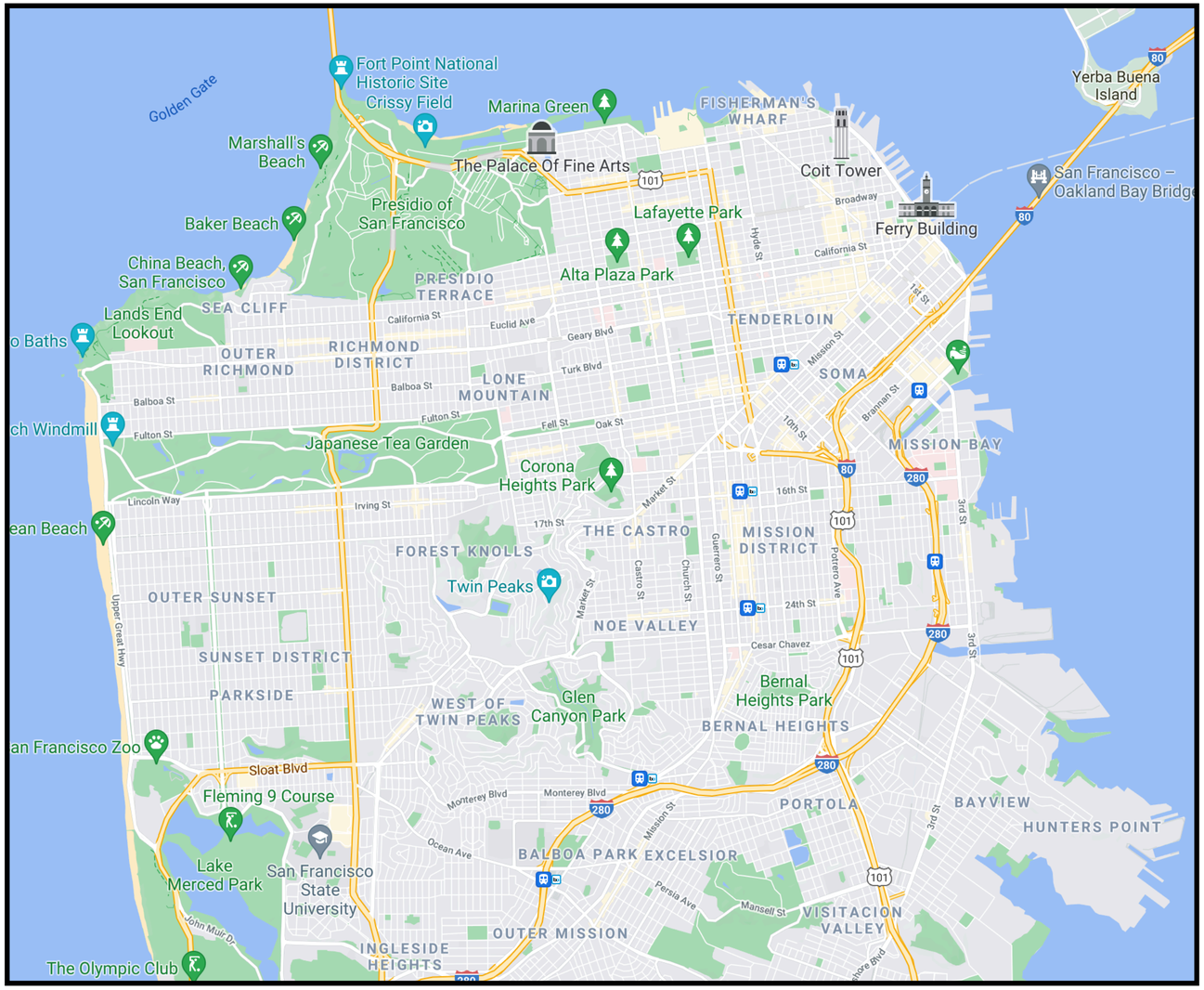
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



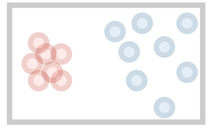
Spatio-temporal diversity of tasks



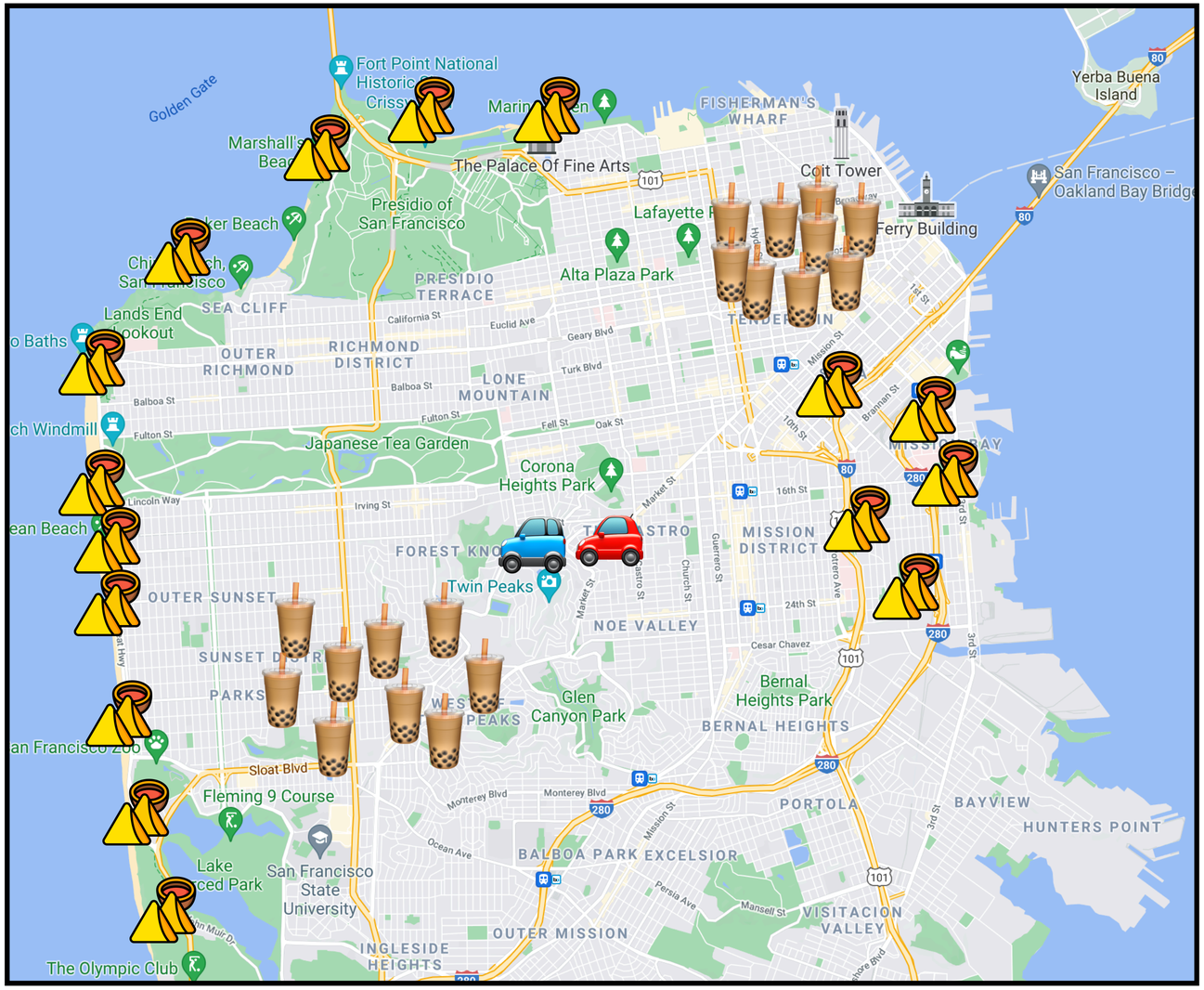
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



Spatio-temporal diversity of tasks



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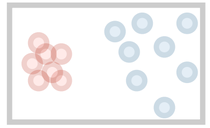
Attributing vehicle time to customer

Timescale of fairness



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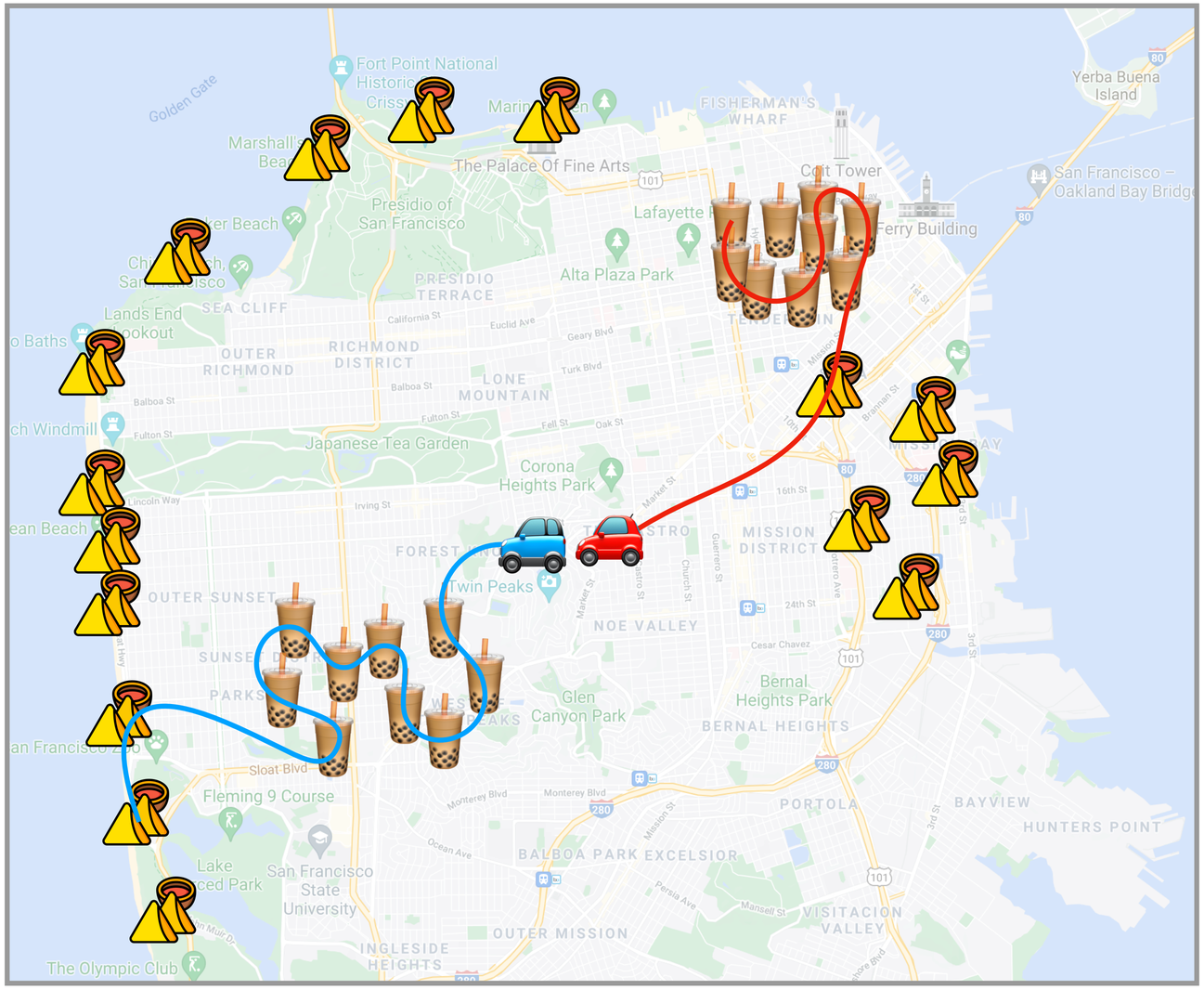


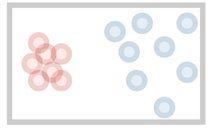
Max Throughput

	17 orders
	3 orders
Total	20 orders

Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



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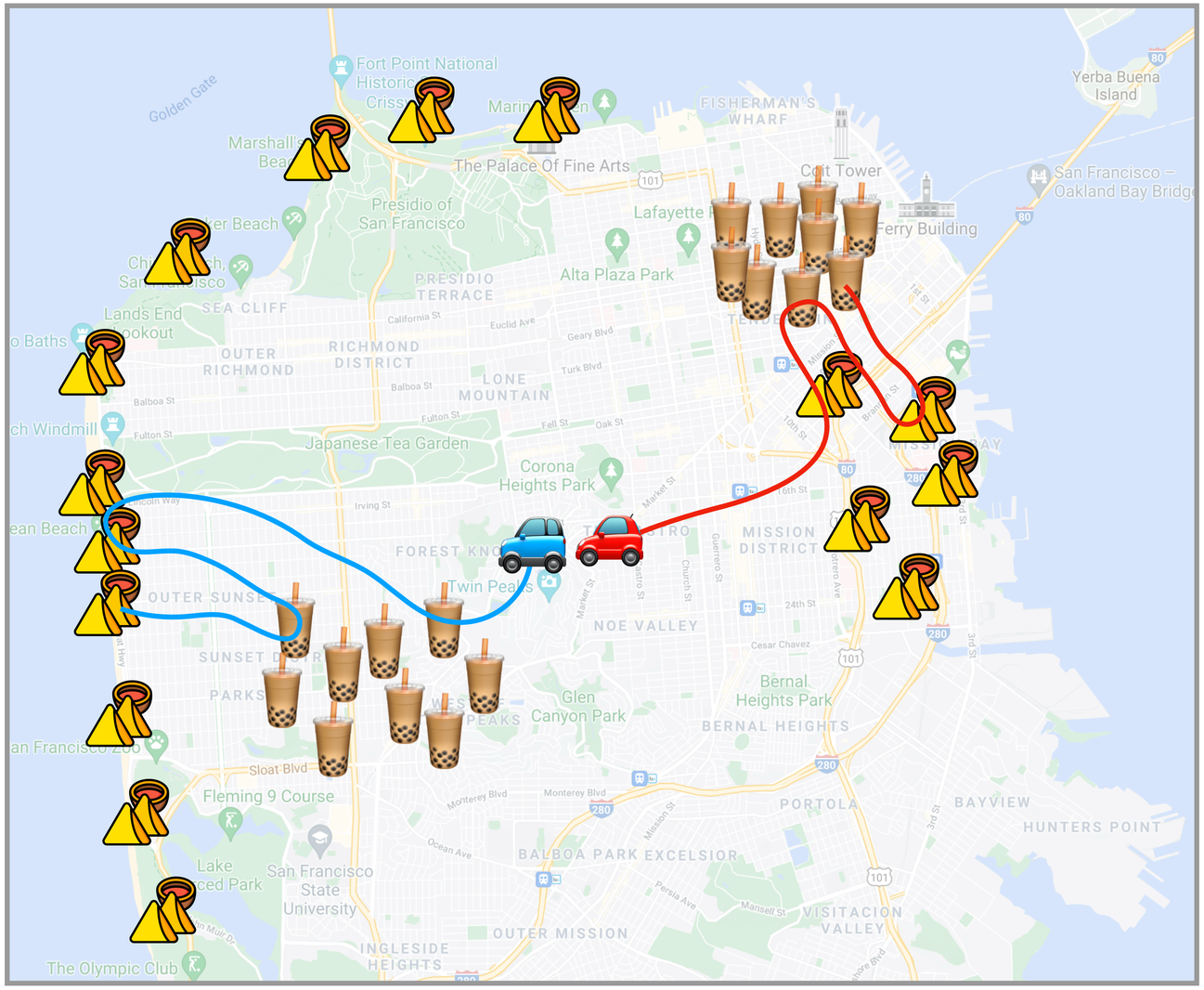


Max Throughput

	17 orders
	3 orders
Total	20 orders

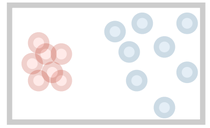
Round Robin

	4 orders
	4 orders
Total	8 orders

Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



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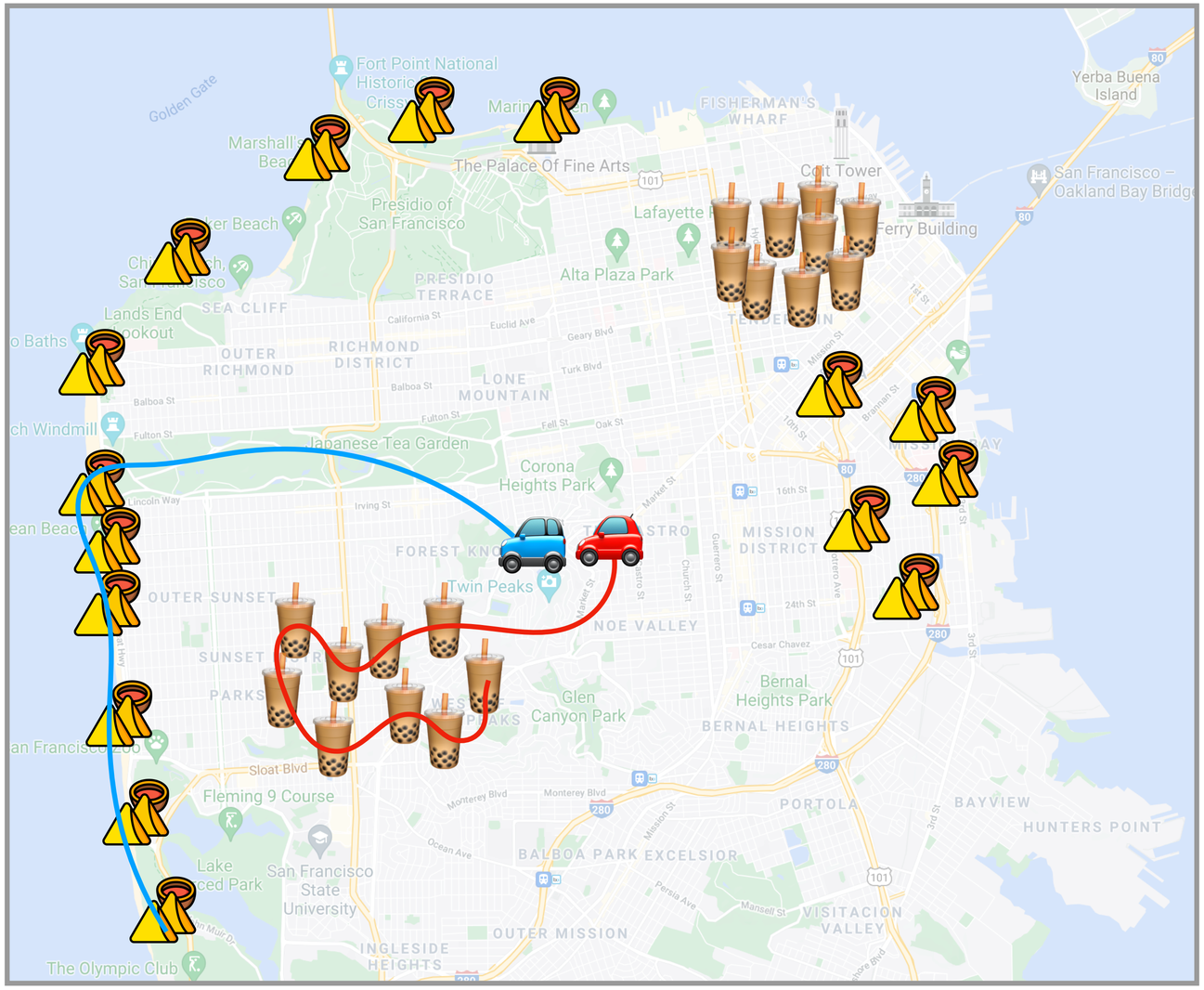


Max Throughput

	17 orders
	3 orders
Total	20 orders

Round Robin

	4 orders
	4 orders
Total	8 orders

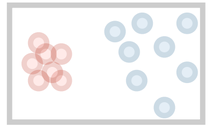
Dedicated

	9 orders
	6 orders
Total	15 orders

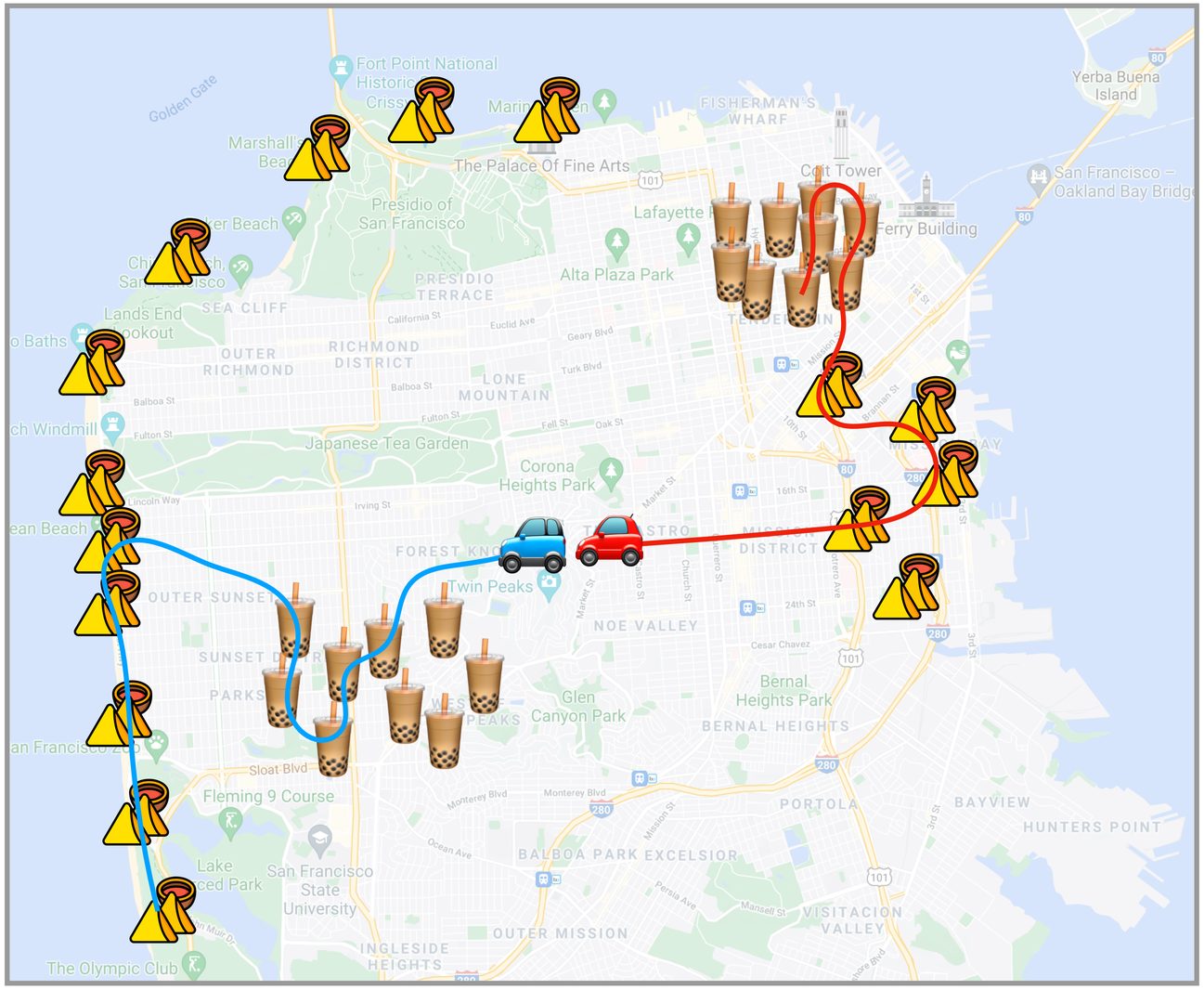
Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



Spatio-temporal diversity of tasks

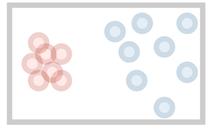


Max Throughput	
	16 orders
	4 orders
Total	20 orders
Round Robin	
	4 orders
	4 orders
Total	8 orders
Dedicated	
	9 orders
	6 orders
Total	15 orders
Mobius	
	10 orders
	9 orders
Total	19 orders

Mobility makes fairness challenging

Attributing vehicle time to customer

Timescale of fairness



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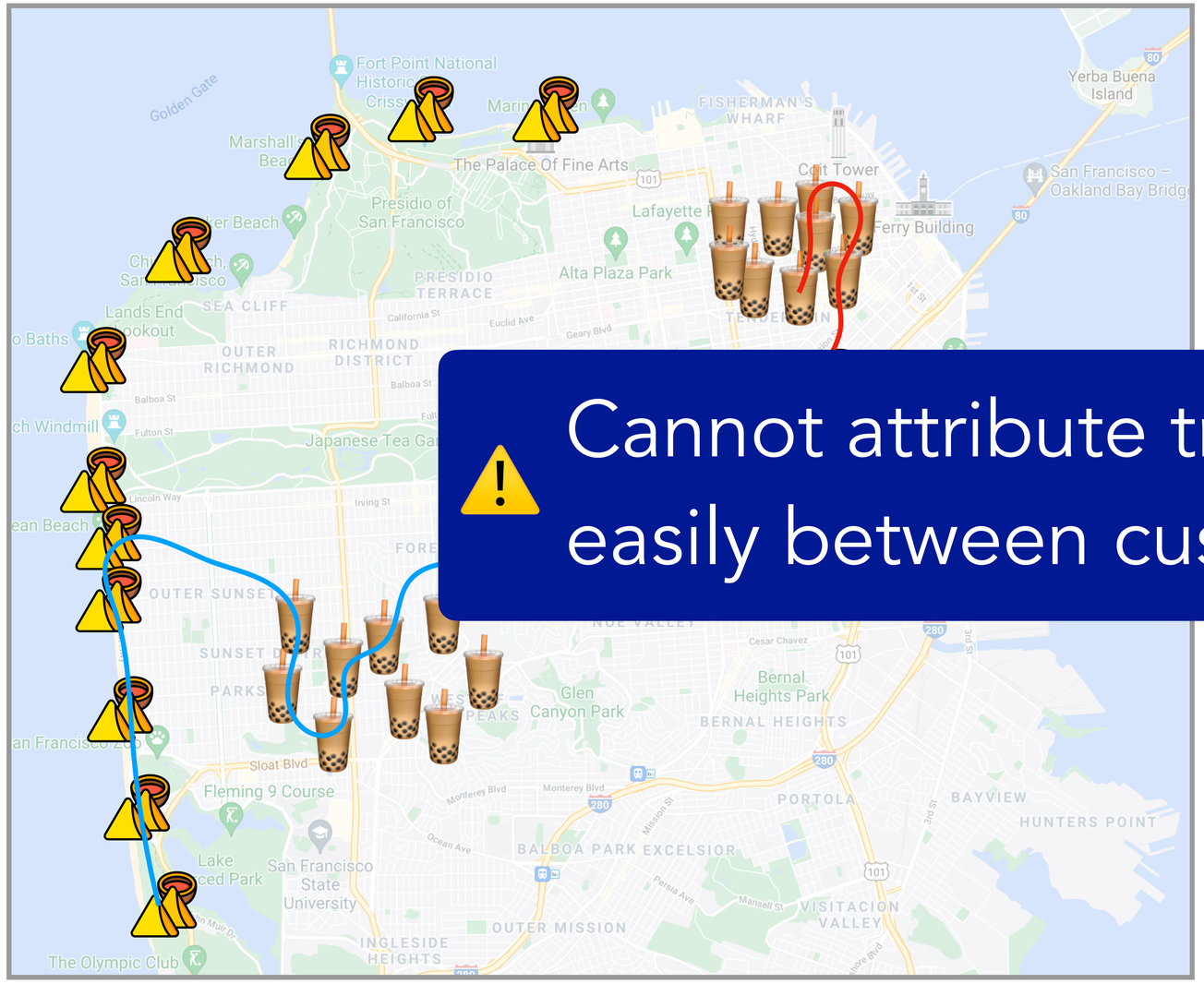


⚠ Cannot attribute travel time easily between customers.

Max Throughput

	16 orders
	4 orders
Total	20 orders

Dedicated

	4 orders
	4 orders
Total	8 orders

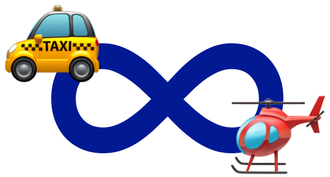
	9 orders
	6 orders
Total	15 orders

Mobius

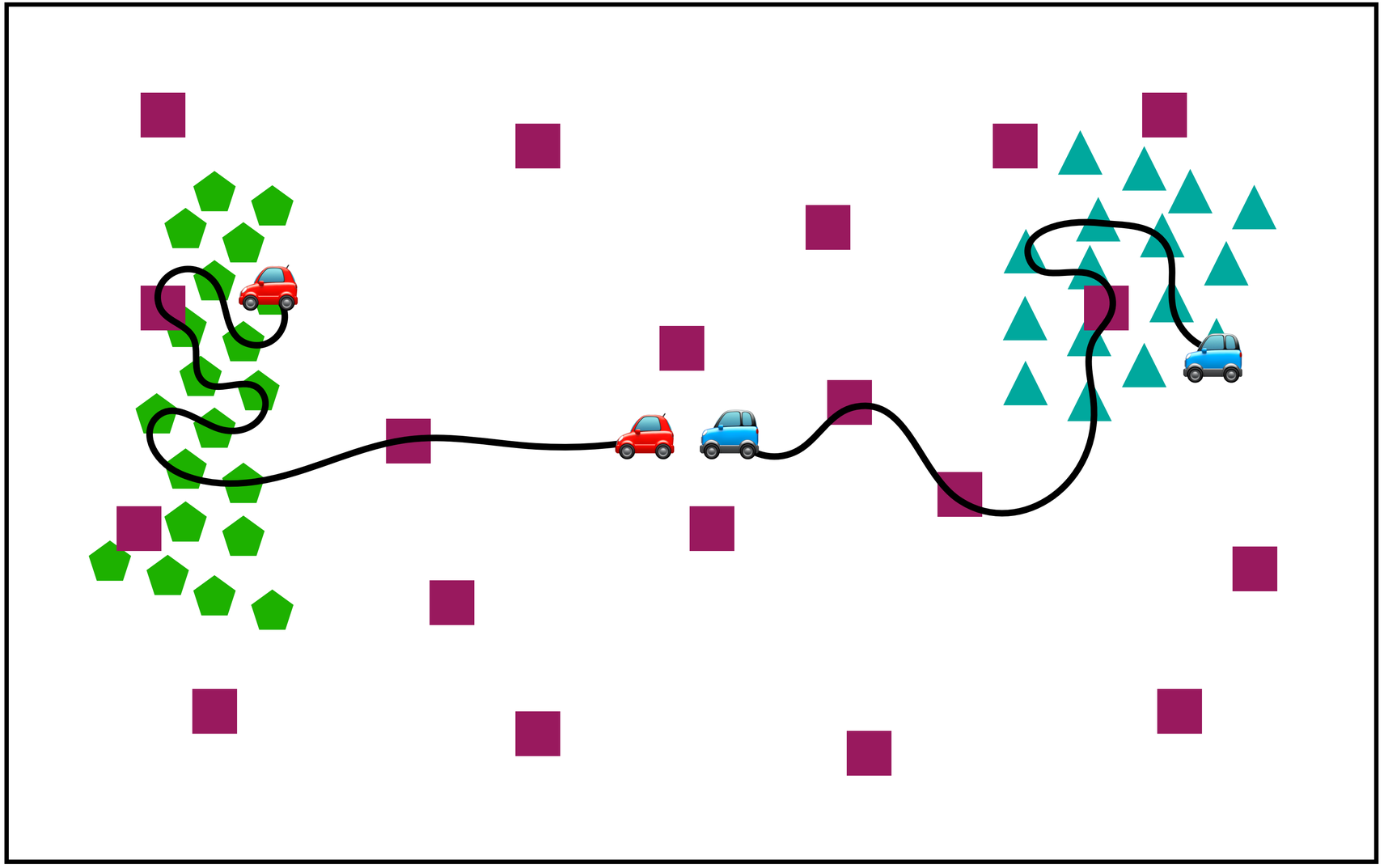
	10 orders
	9 orders
Total	19 orders

Mobius = mobi(lity) + us

An online scheduler that delivers high throughput and fairness.



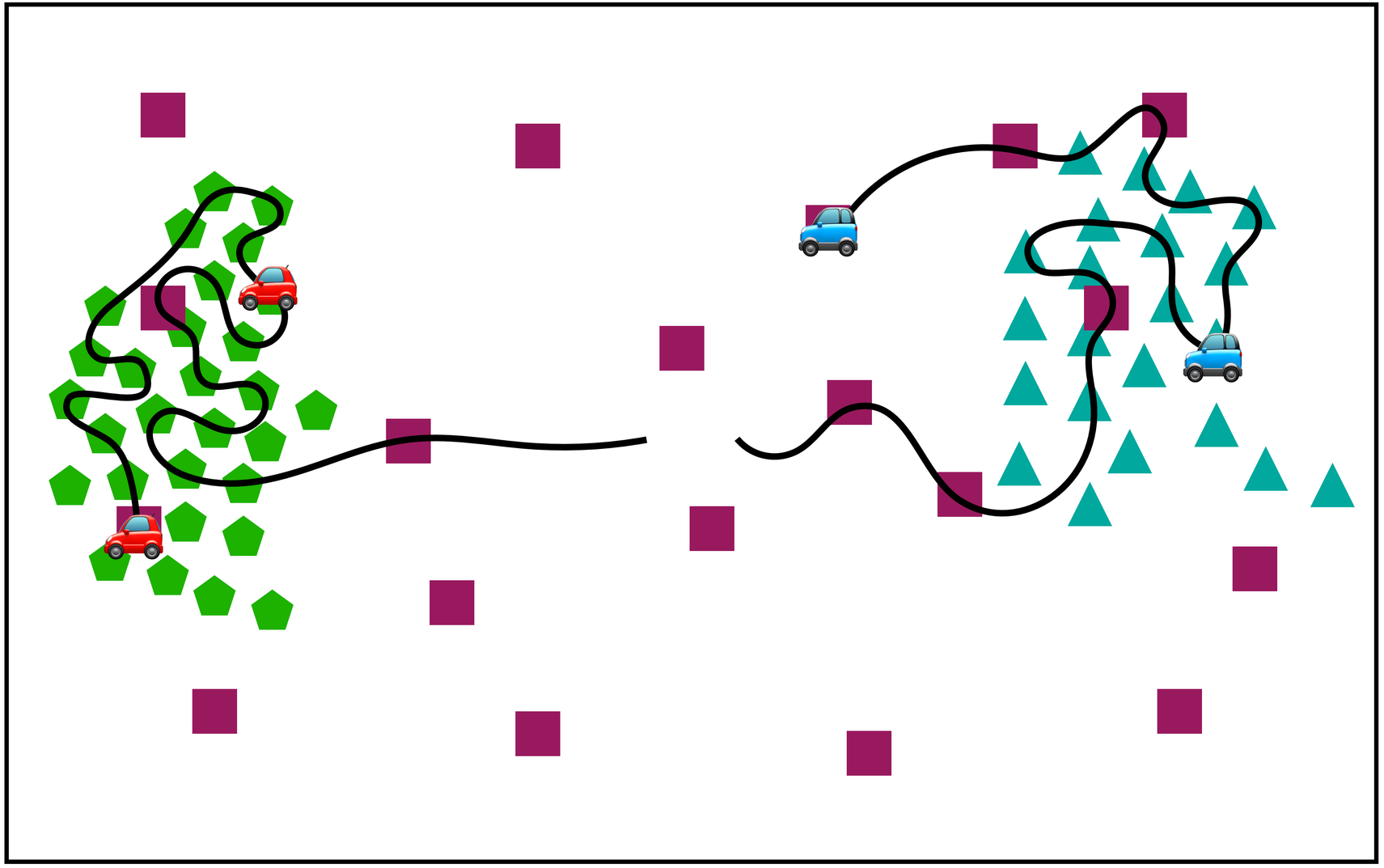
Problem setup



Customer Tasks

Vehicles

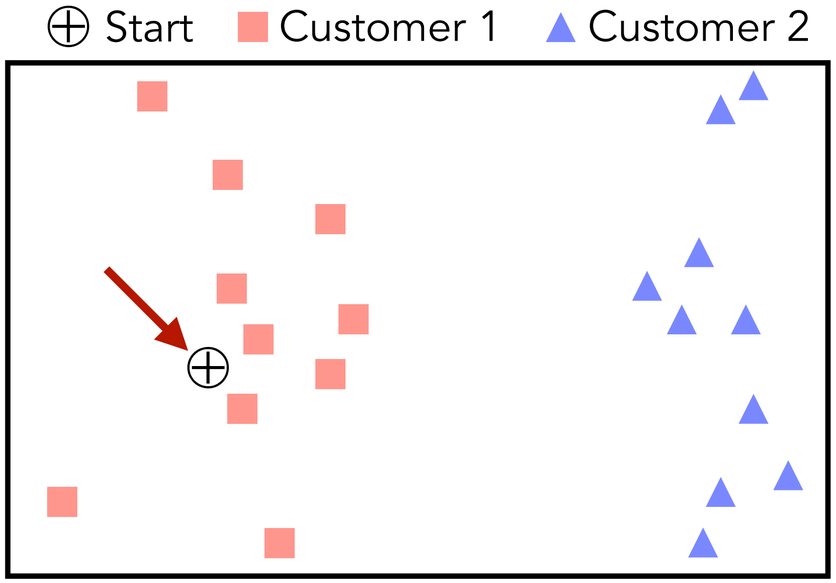
Problem setup



Customer Tasks

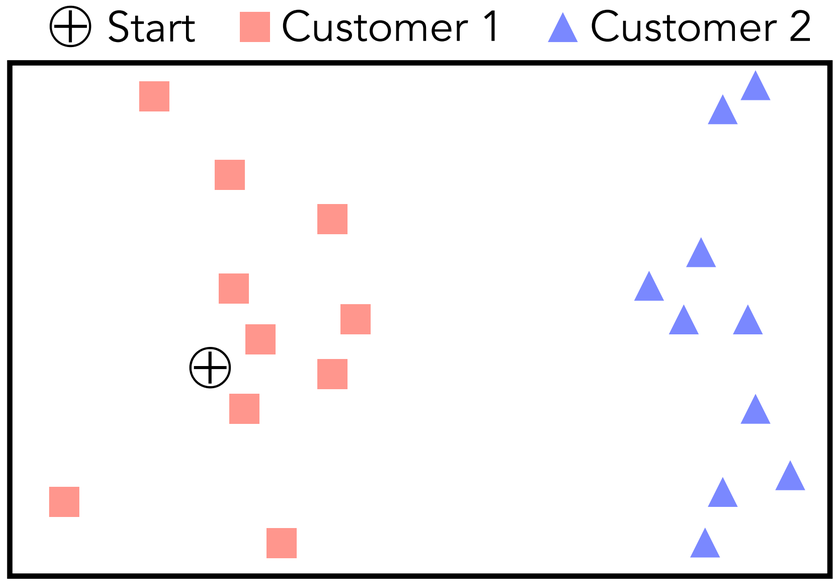
Vehicles

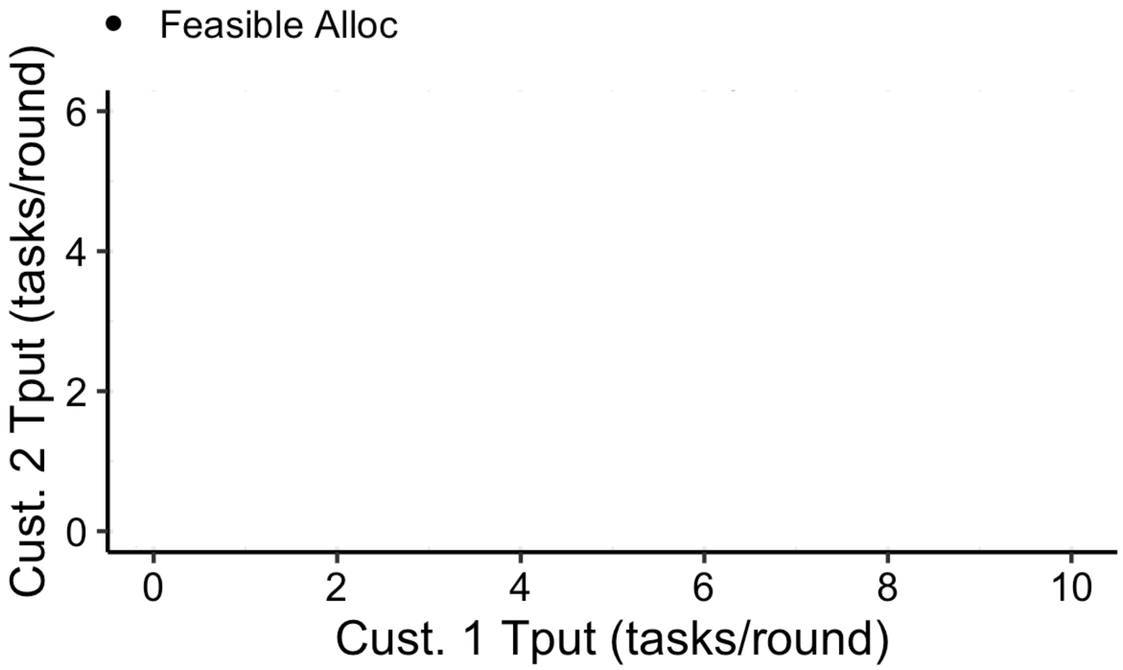
An illustrative example



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

Feasible schedules





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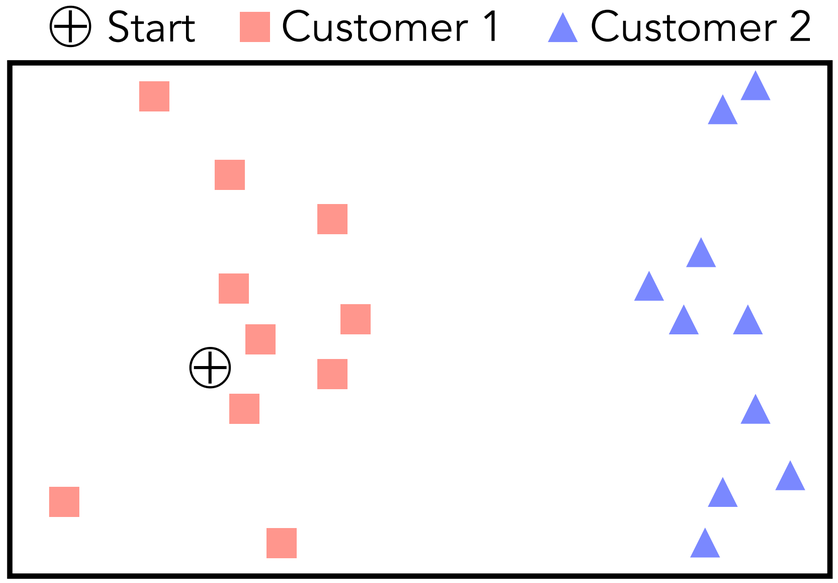
Feasible schedules



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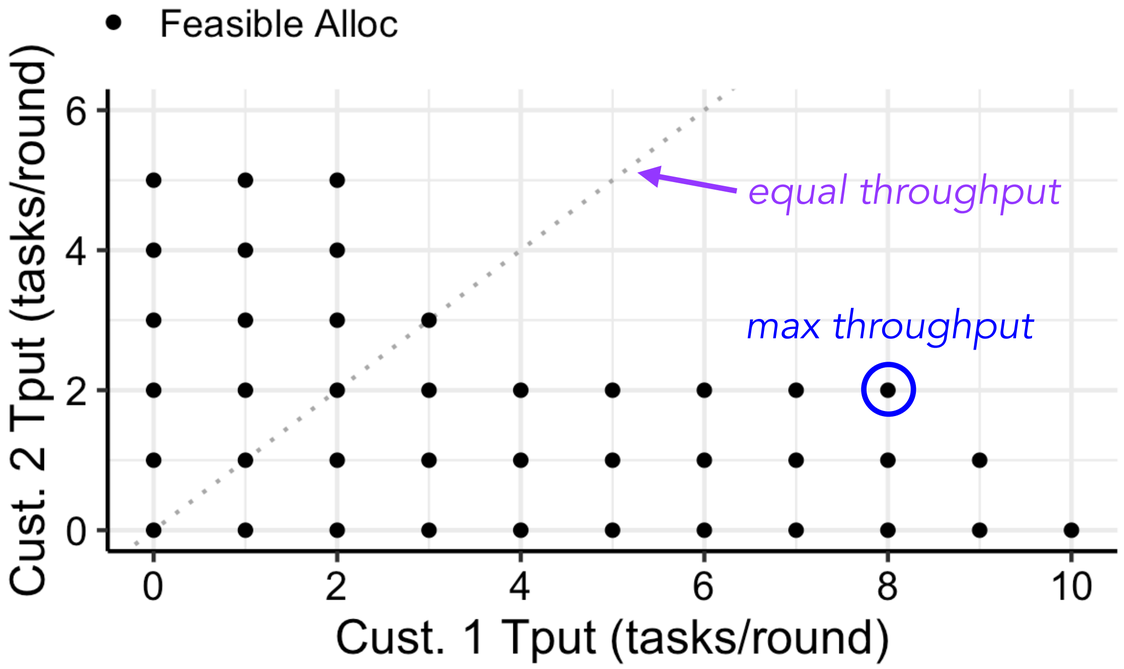
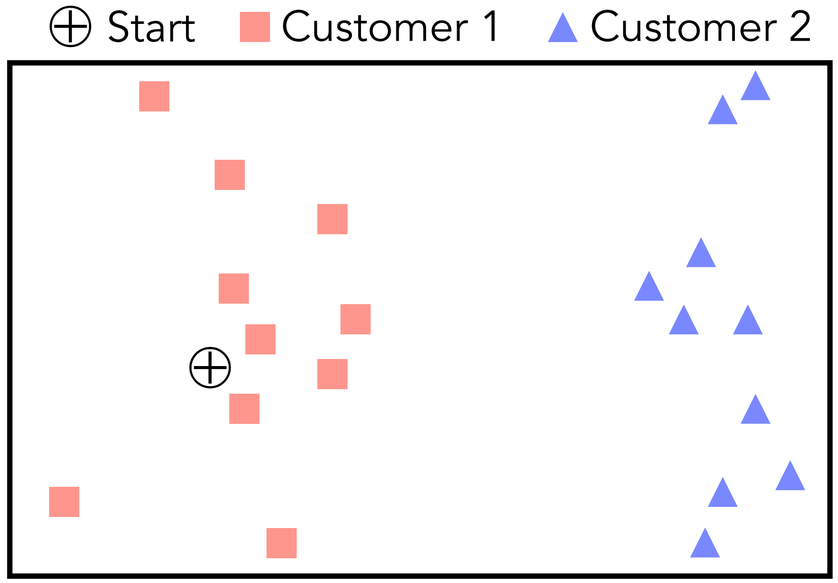


Pareto frontier



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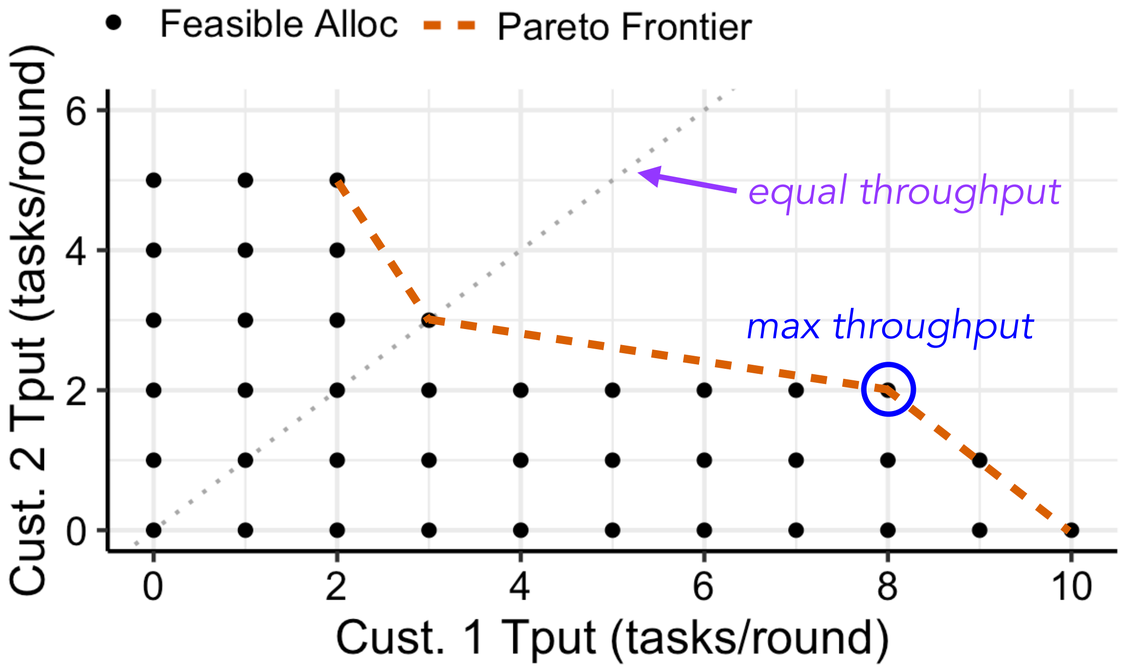

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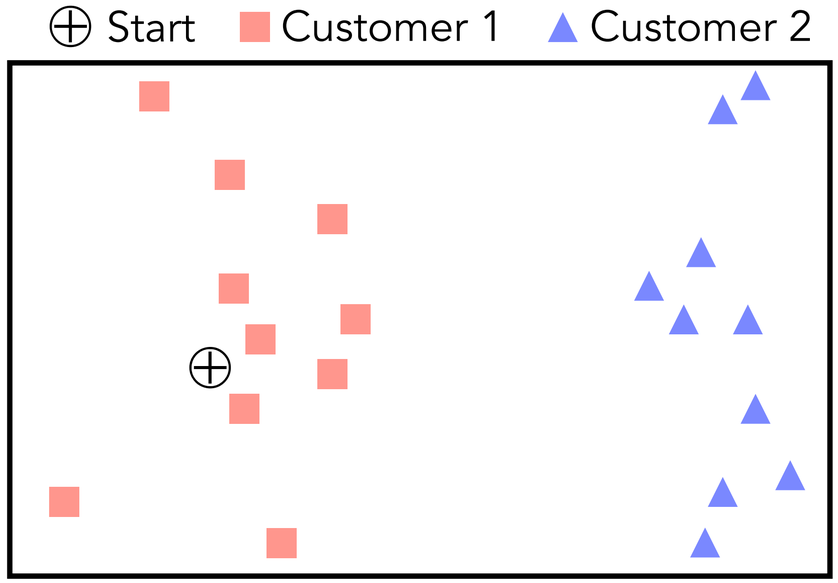

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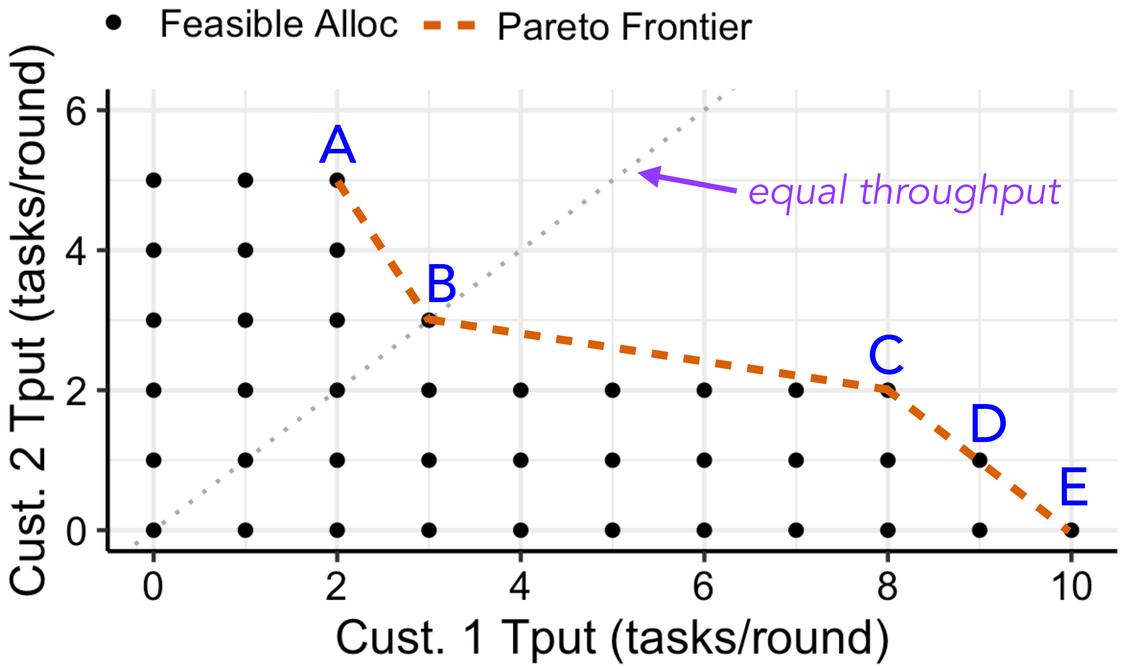
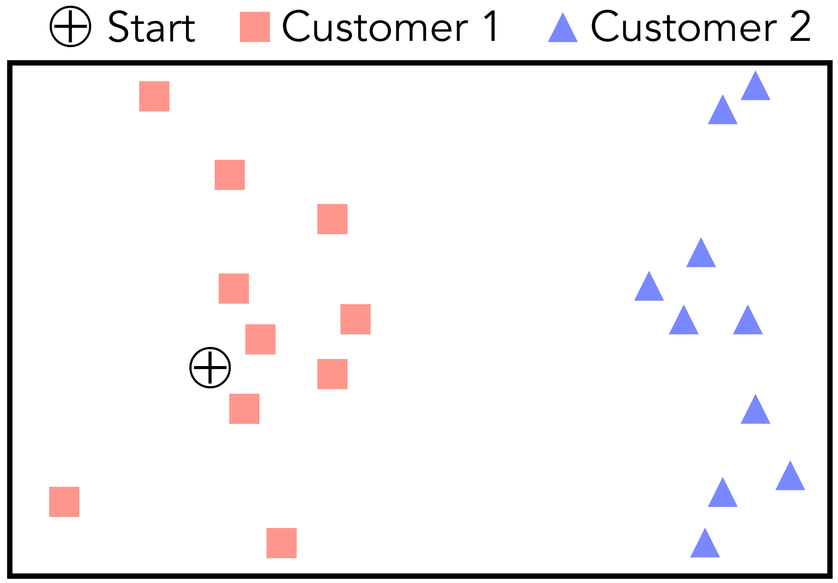


Pareto Frontier: {A, B, C, D, E}

Convex boundary



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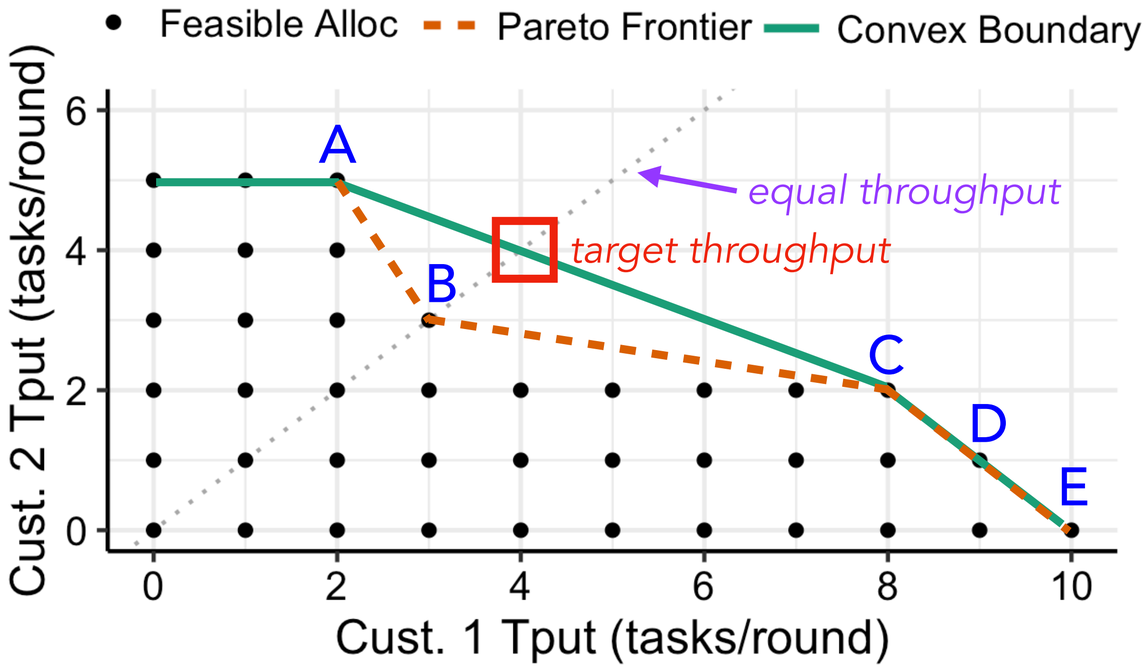
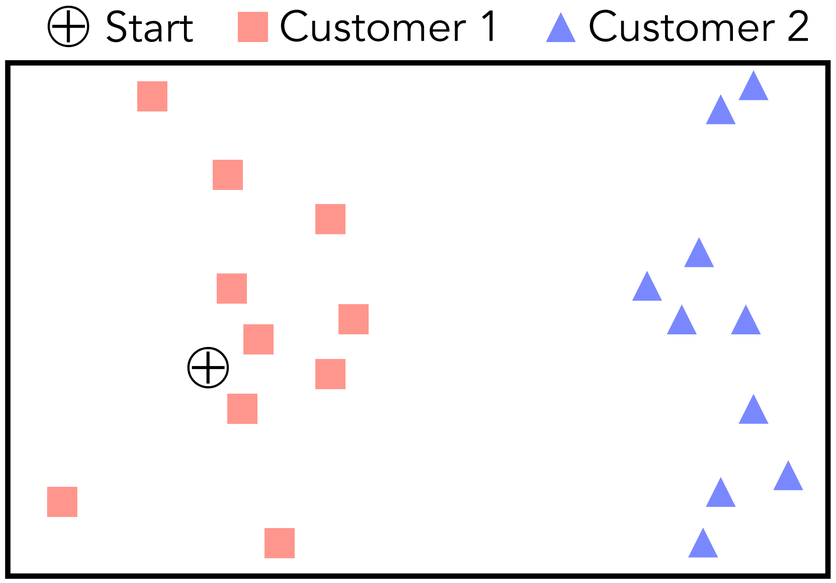


~~**Pareto Frontier:** {A, B, C, D, E}~~

Corner Points: {A, C, D, E}

Convex boundary



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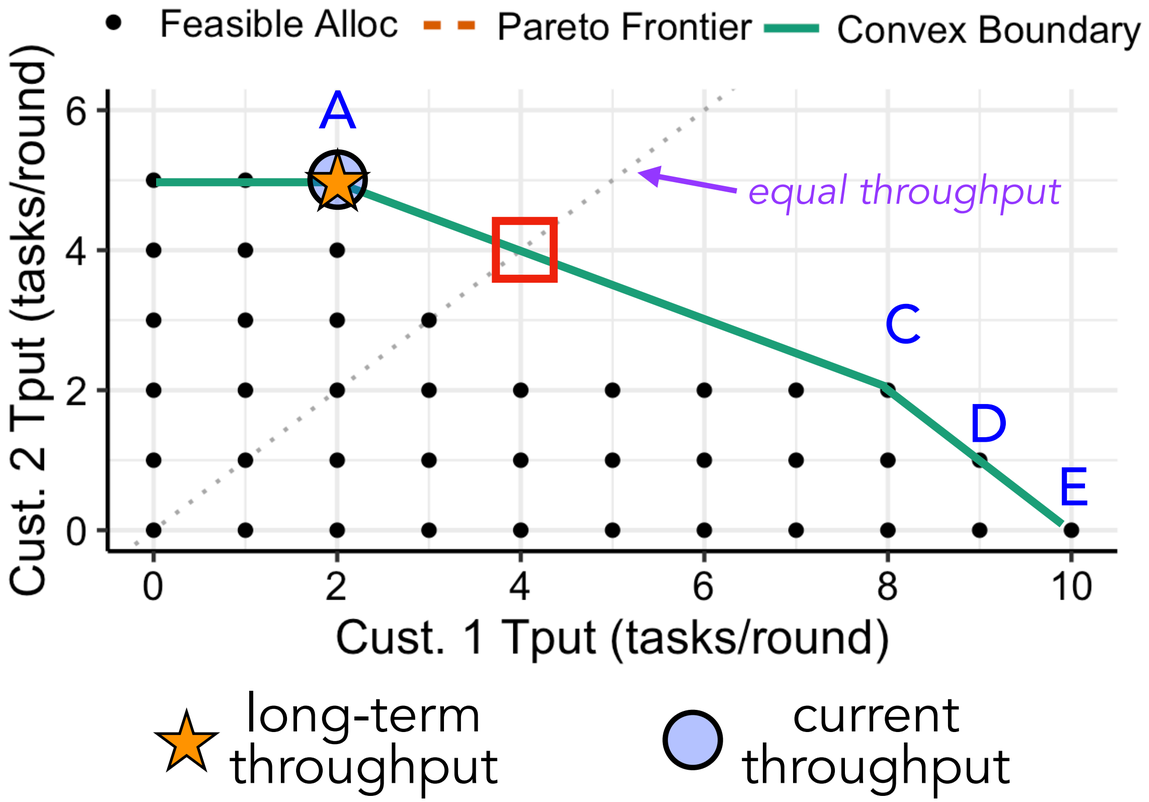
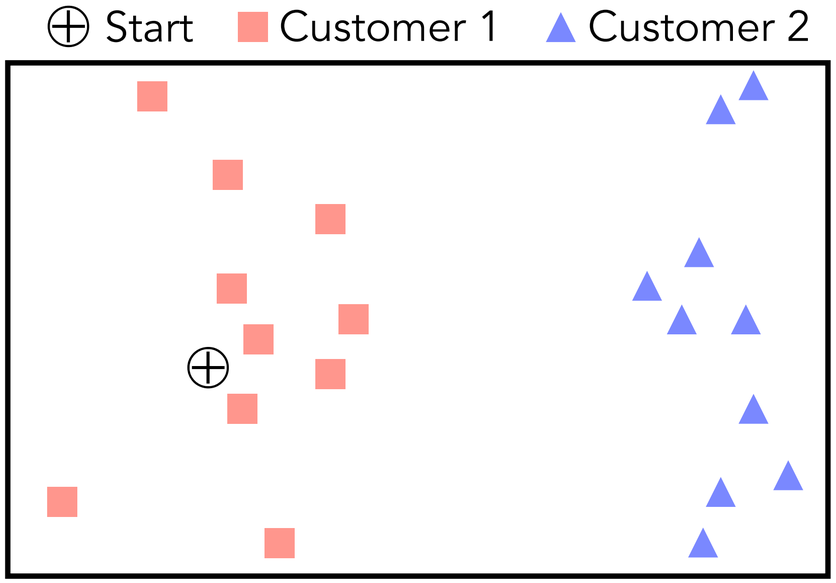


long-term throughput

current throughput

Corner Points: {A, C, D, E}

Convex boundary



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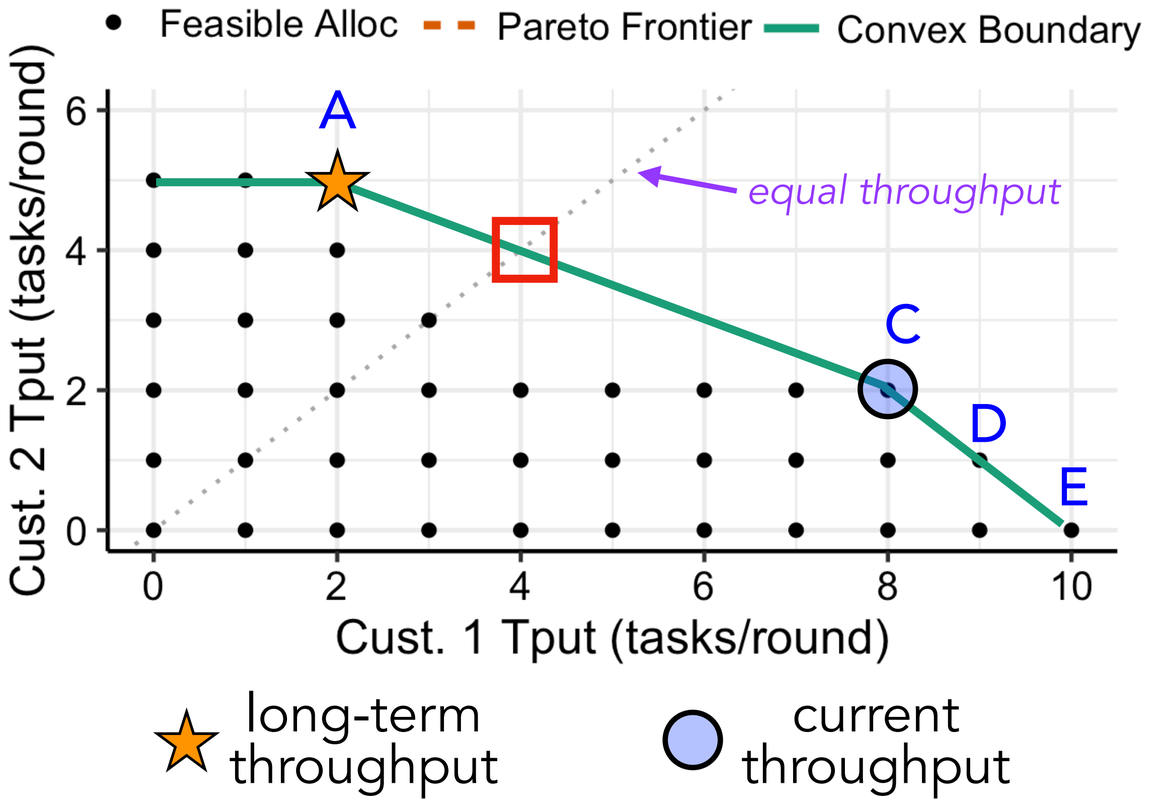

long-term throughput

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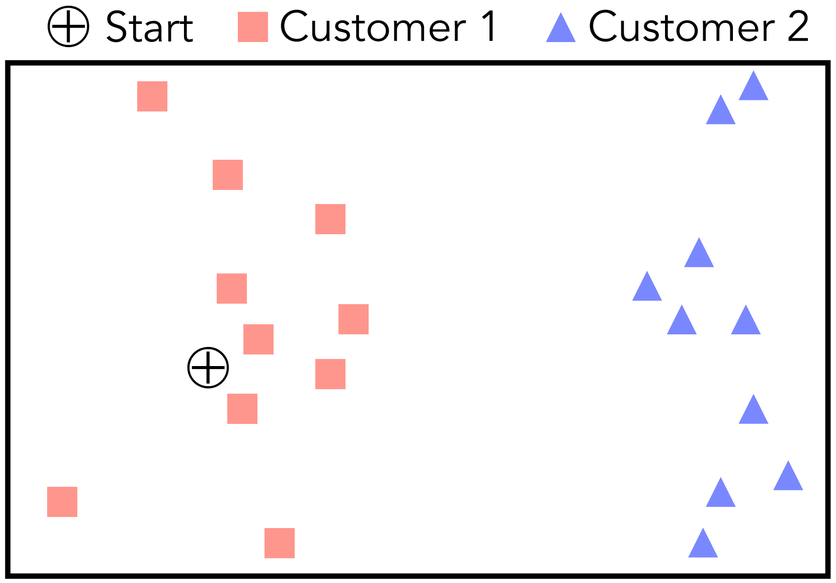
Corner Points: {A, C, D, E}

Convex boundary



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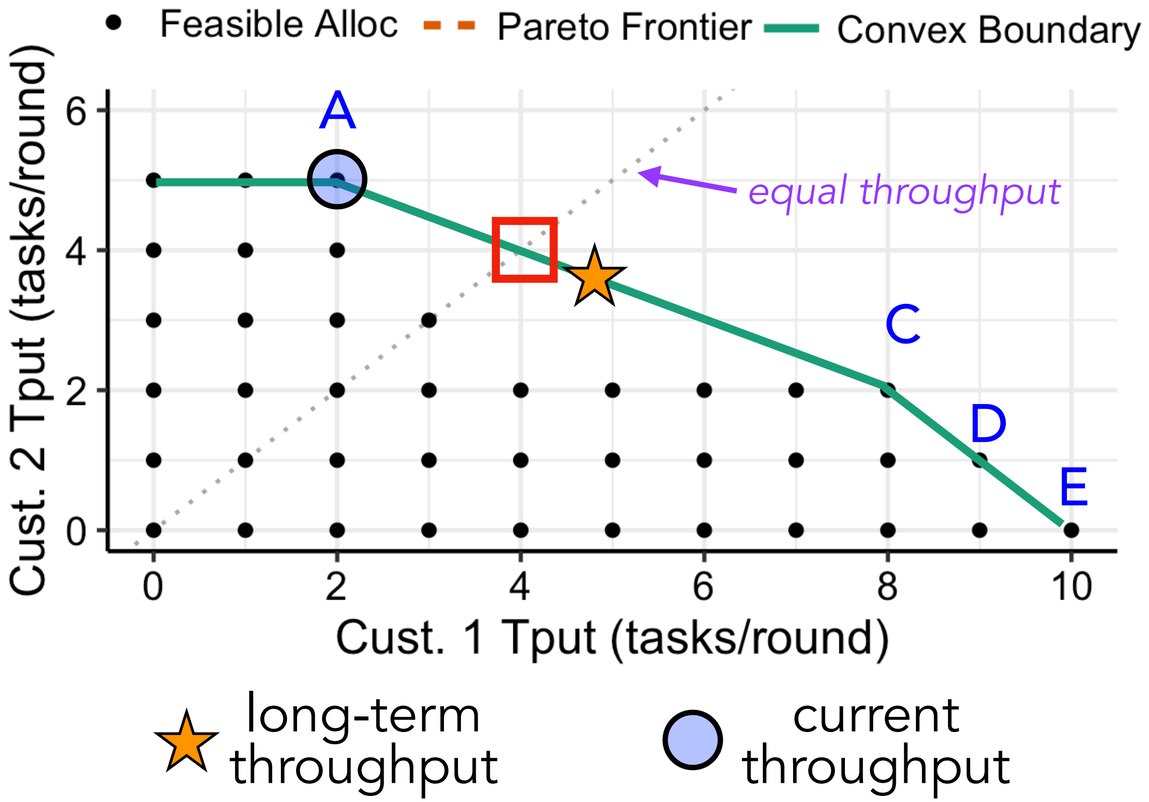
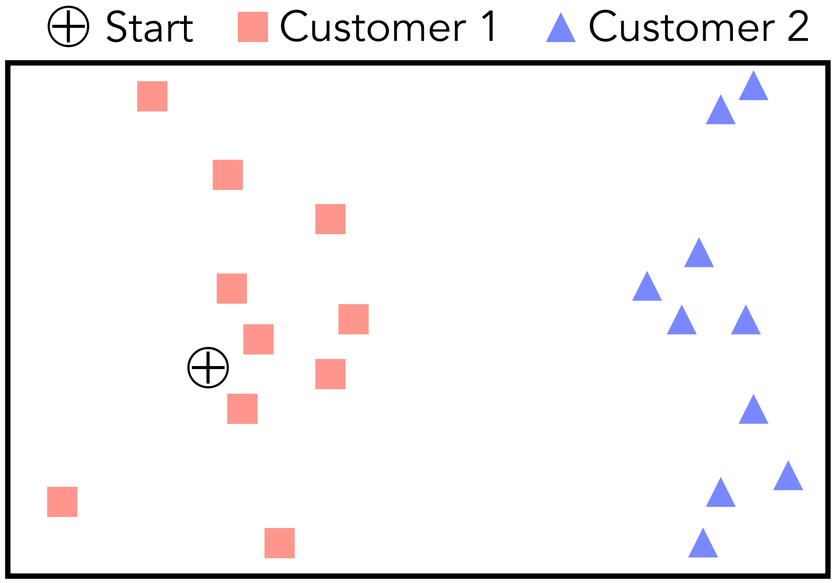


Convex boundary



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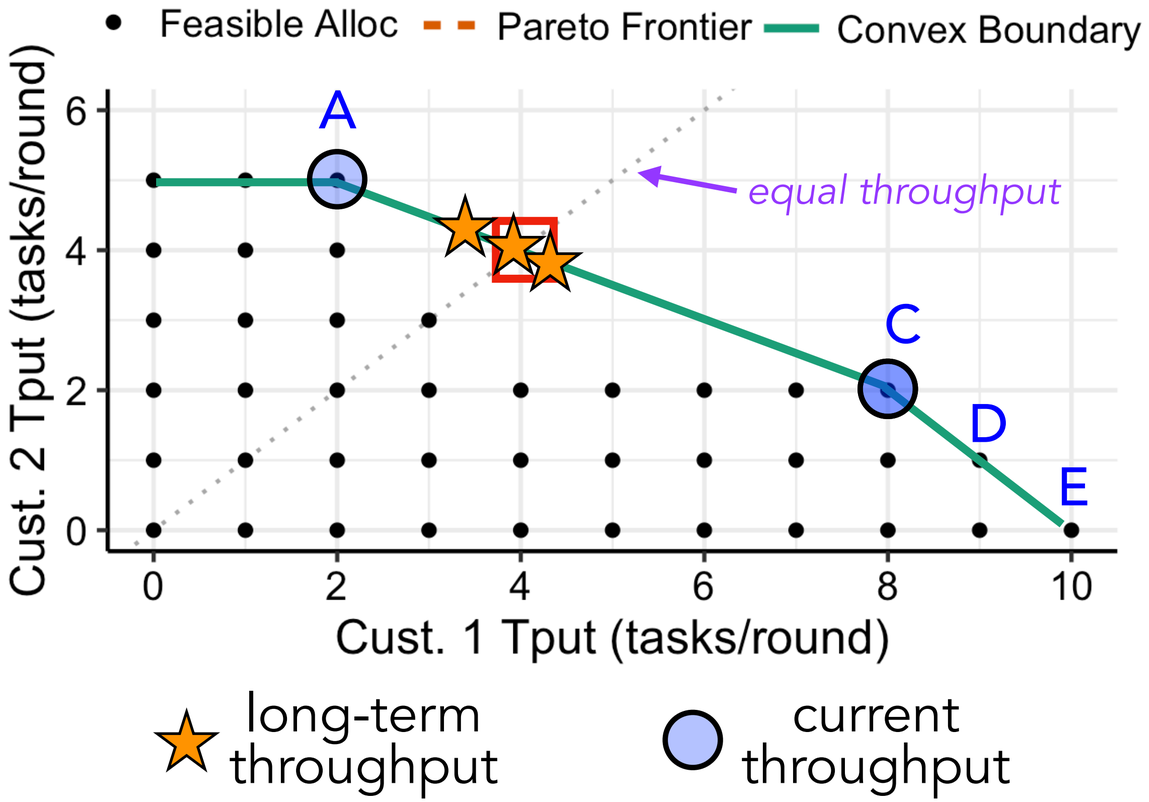
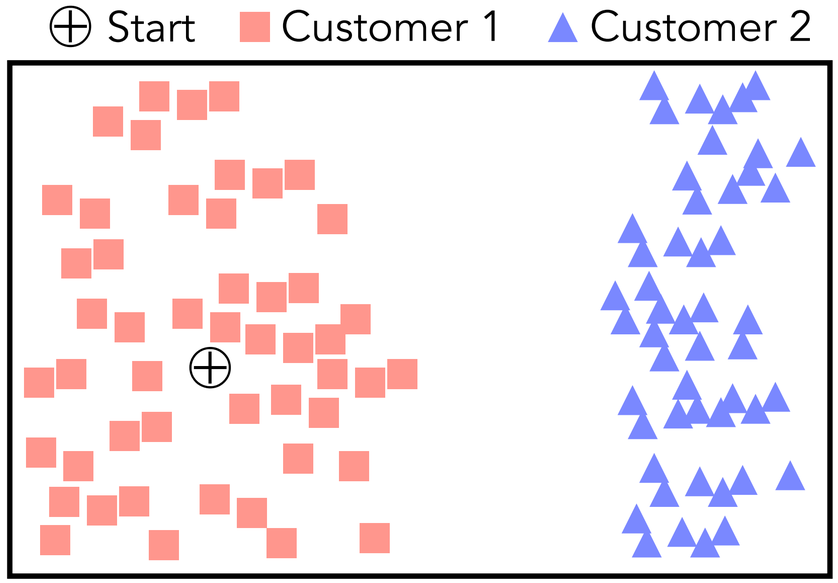
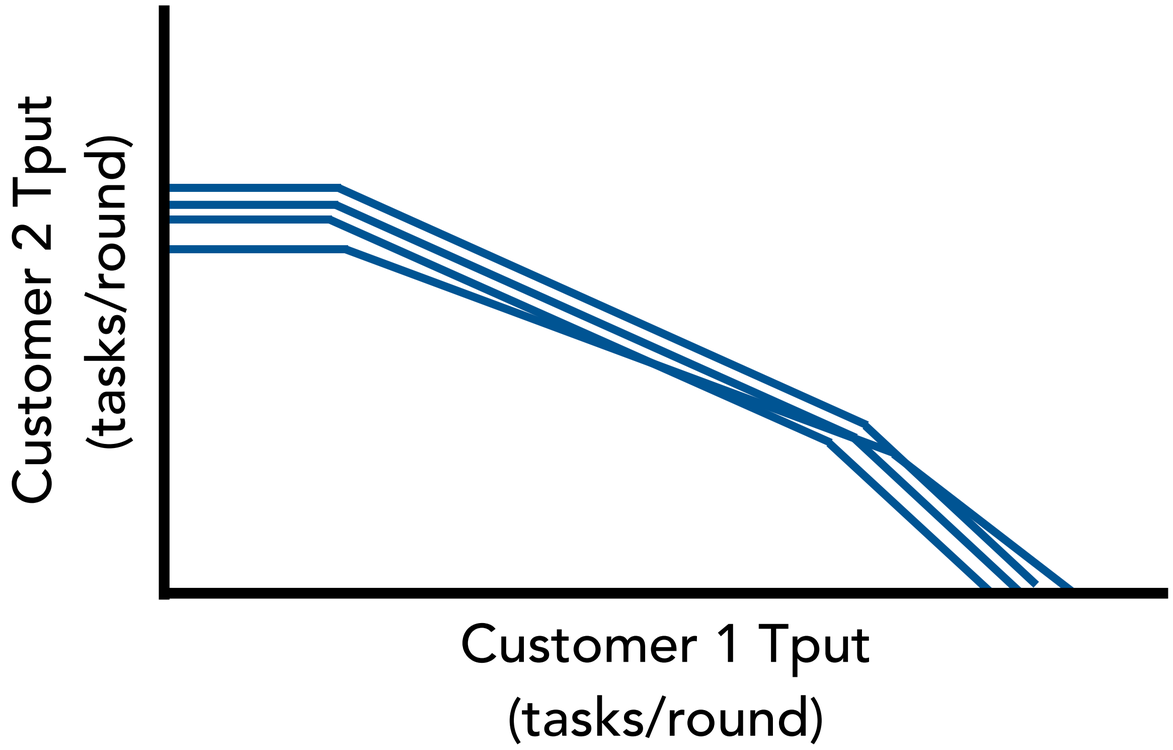


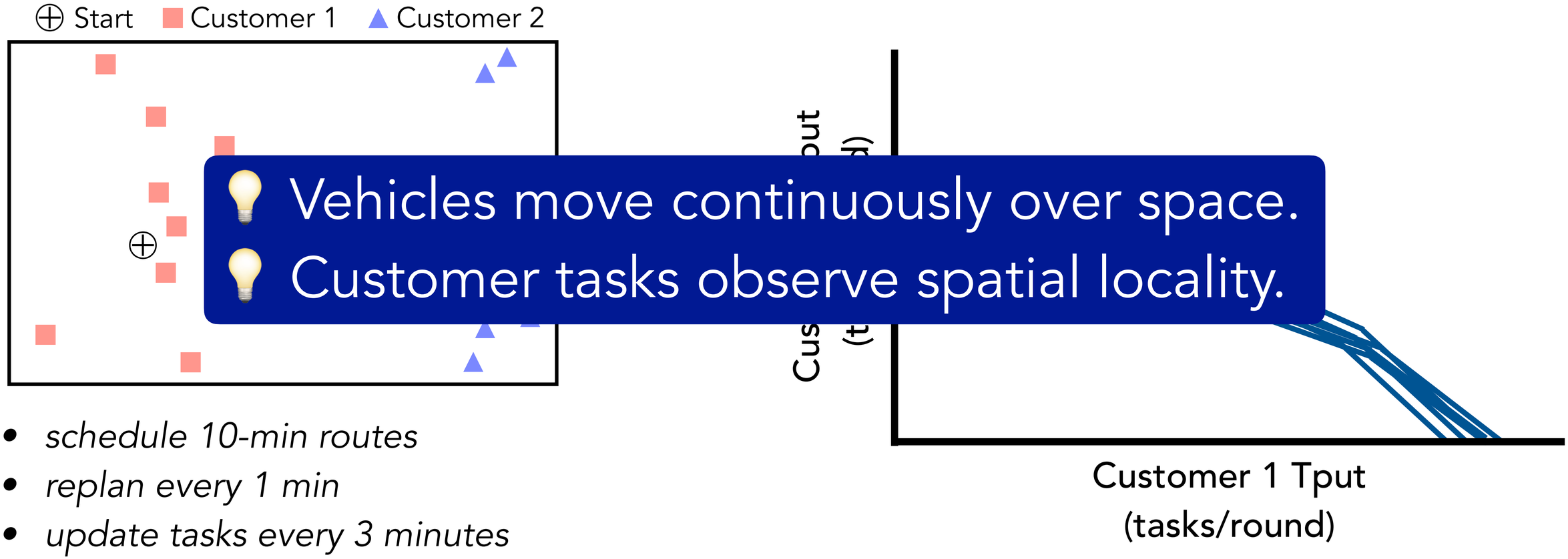
Dynamic environments



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



Dynamic environments

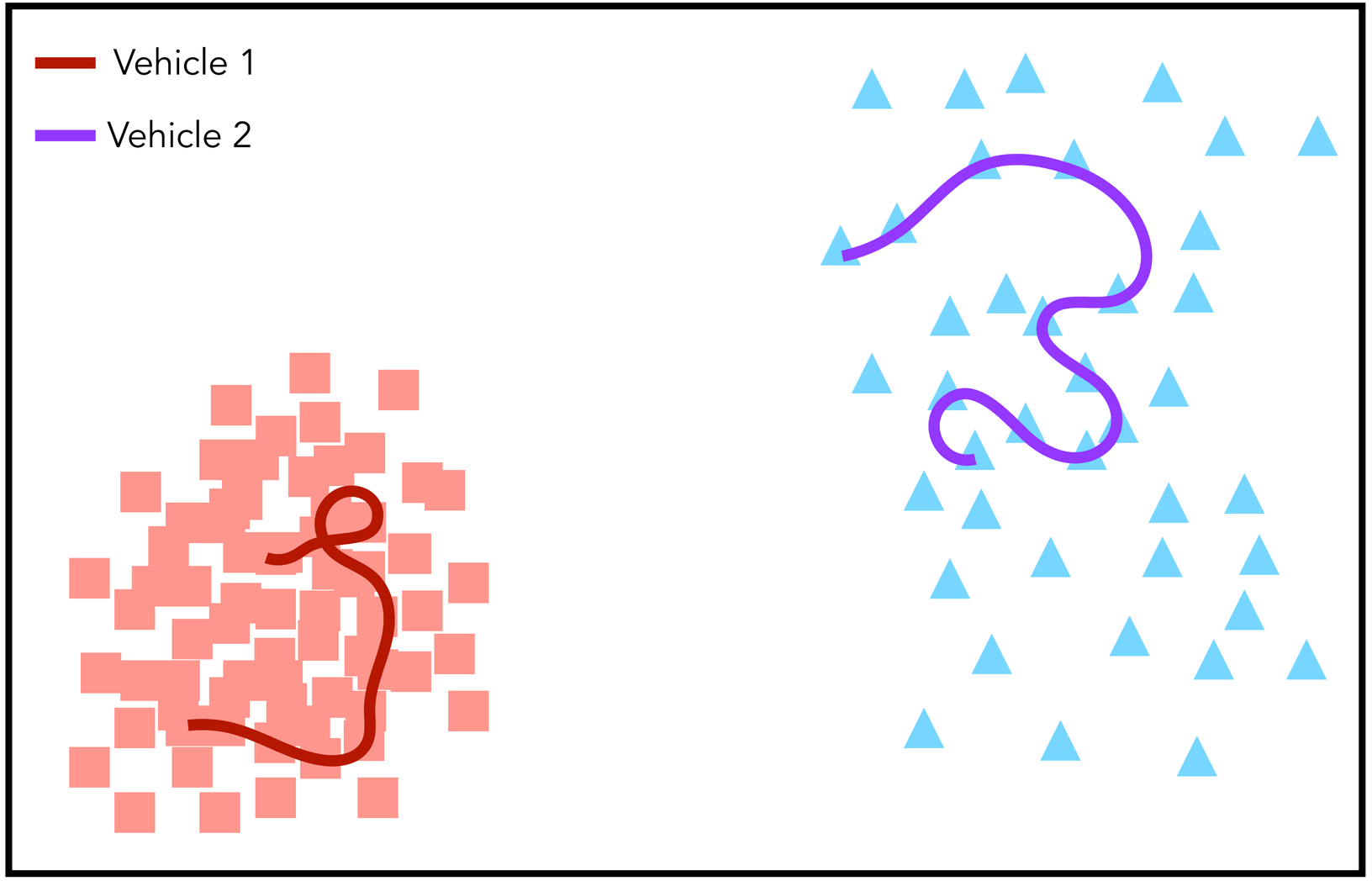


- *schedule 10-min routes*
- *replan every 1 min*
- *update tasks every 3 minutes*
  (according to spatial distribution in map)

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.

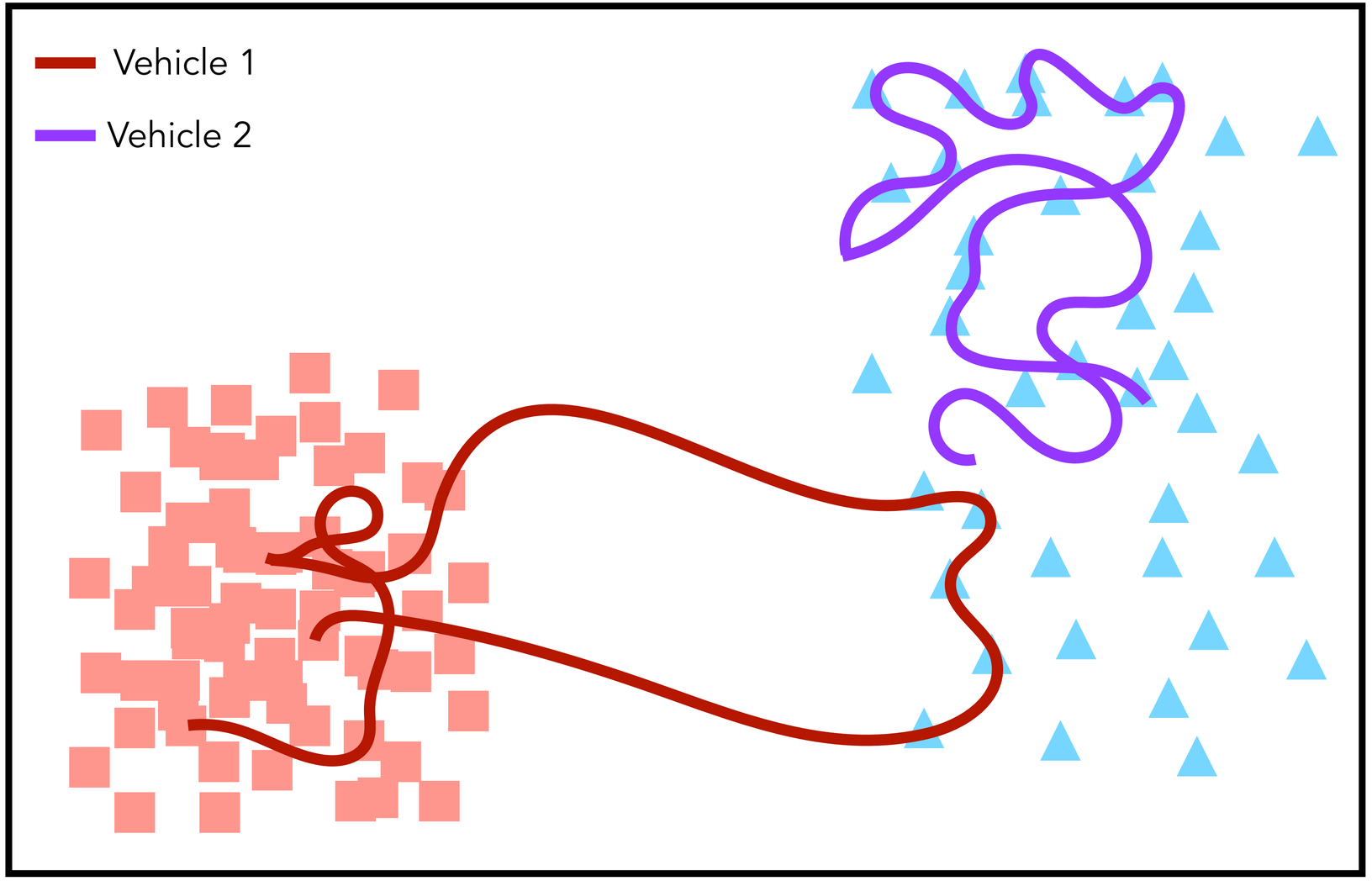
Mobius in action



After Round 1

	18 orders
	12 orders
Total	30 orders

Mobius in action



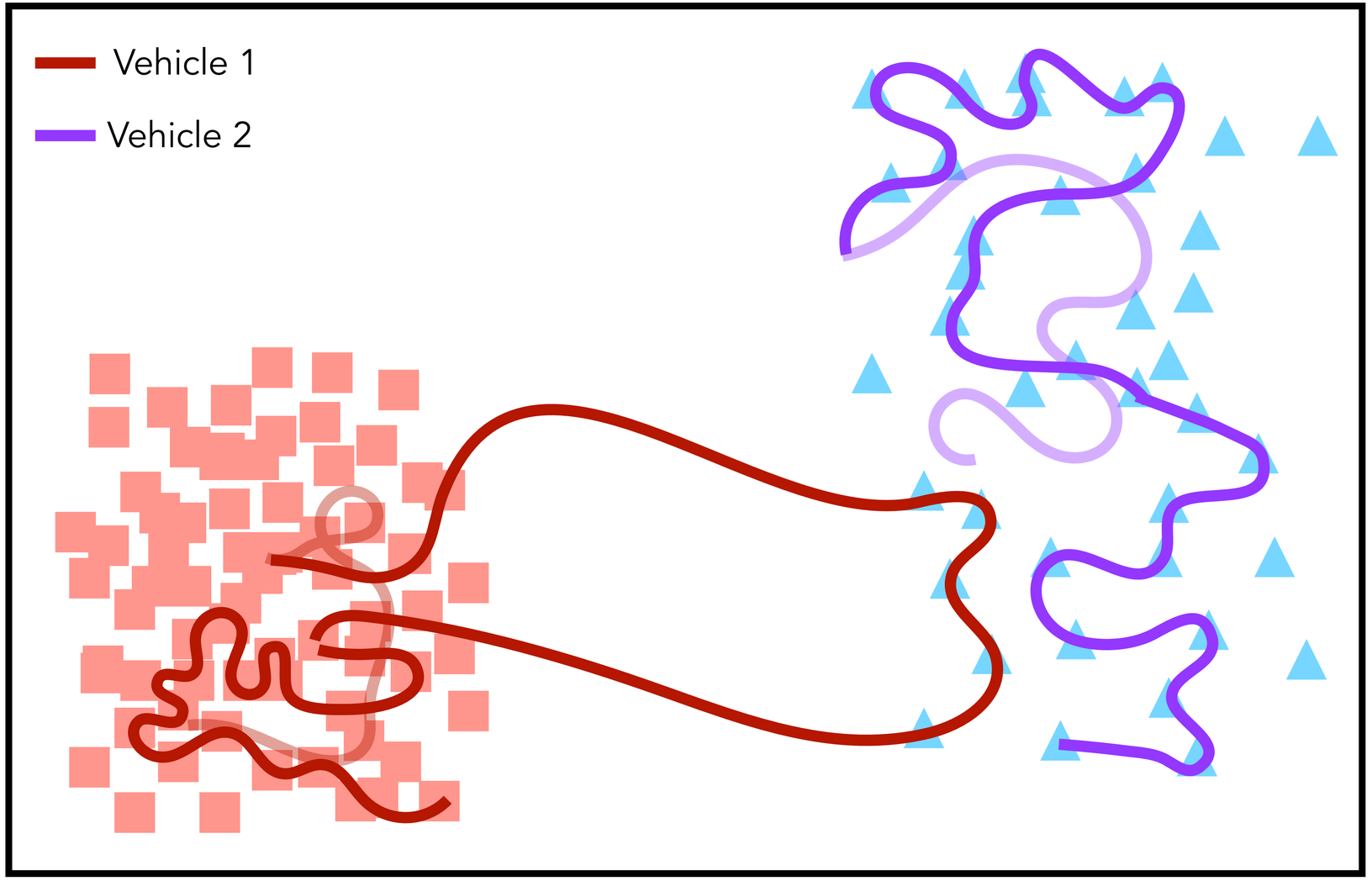
After Round 1

■	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

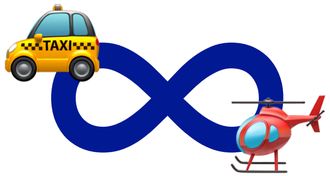
■	49 orders
▲	43 orders
Total	92 orders

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

Implementation

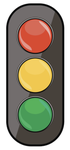
Mobius Scheduler



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

mobius-scheduler/mobius

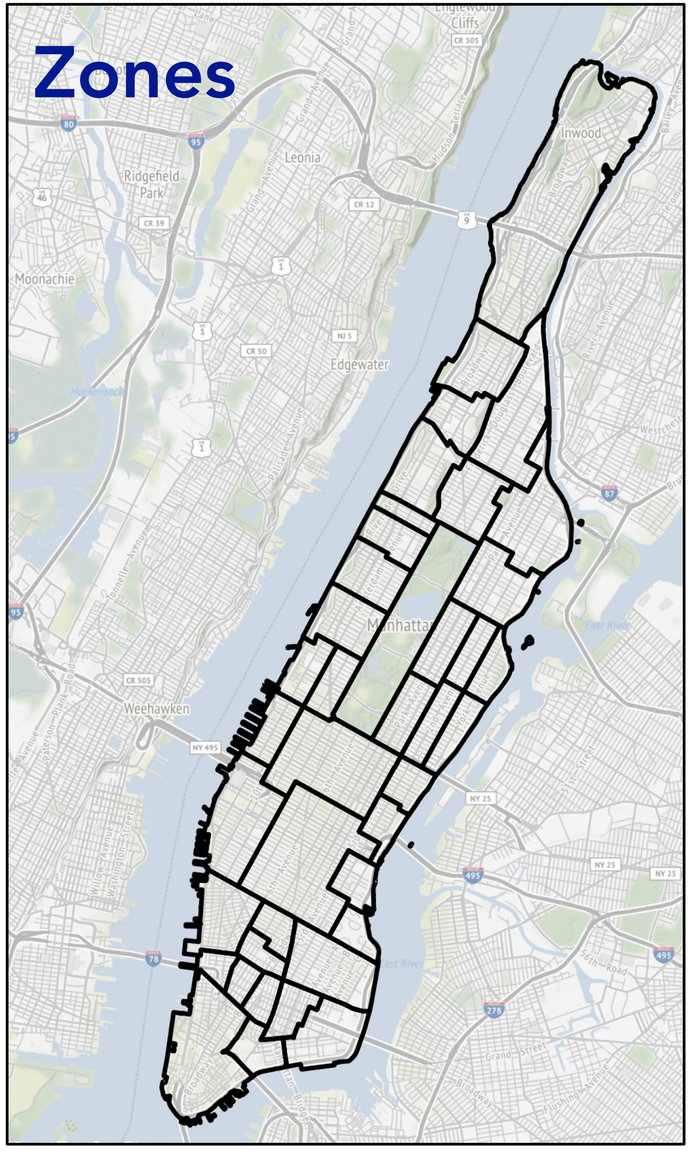
Customers (Apps)

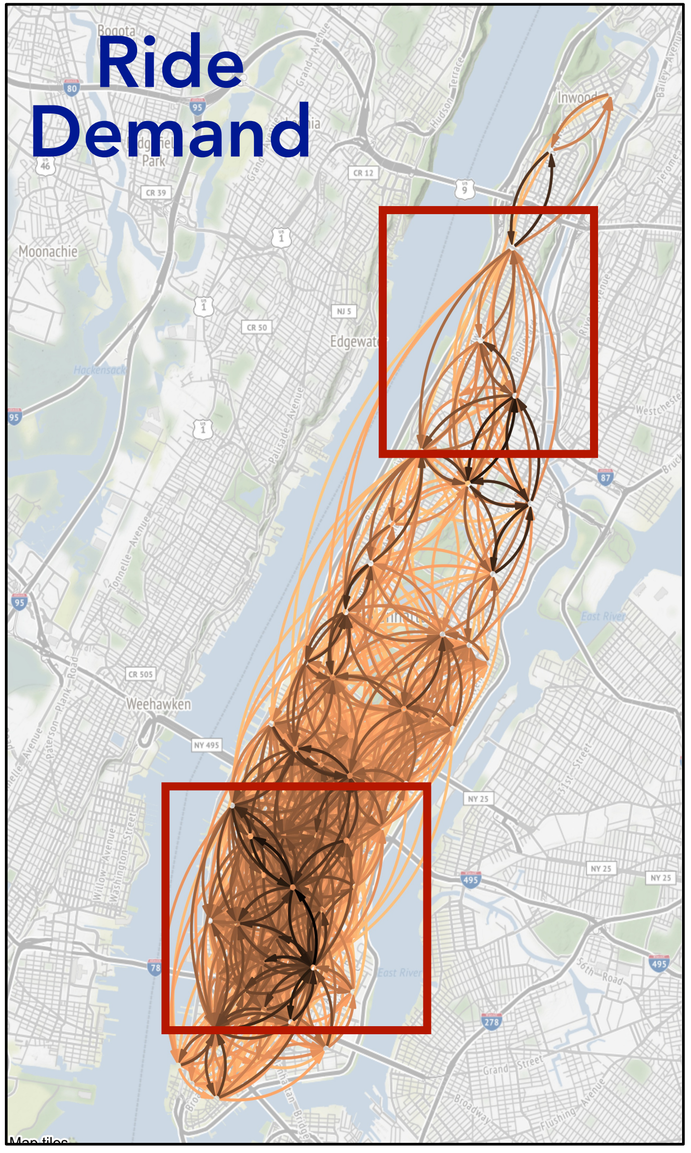


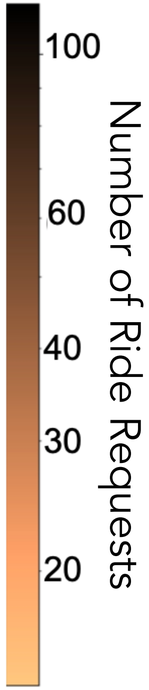
- Apps can be written in Python, Go, etc.
- App logic can rely on ML models

mobius-scheduler/apps

Lyft Ridesharing in Manhattan







Setup

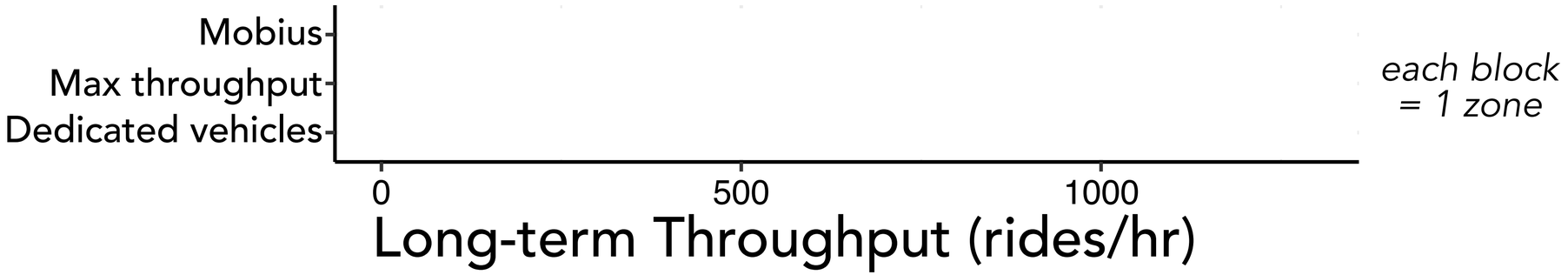
- 13-hour trace
- 16k requests
- 40 neighborhoods (zones)
- 200 vehicles

Want to fulfill pickups from all zones equitably (max-min fairness).

Lyft Ridesharing in Manhattan

heatmap colors:
bright → »tput
homogenous → »fair

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



each block = 1 zone

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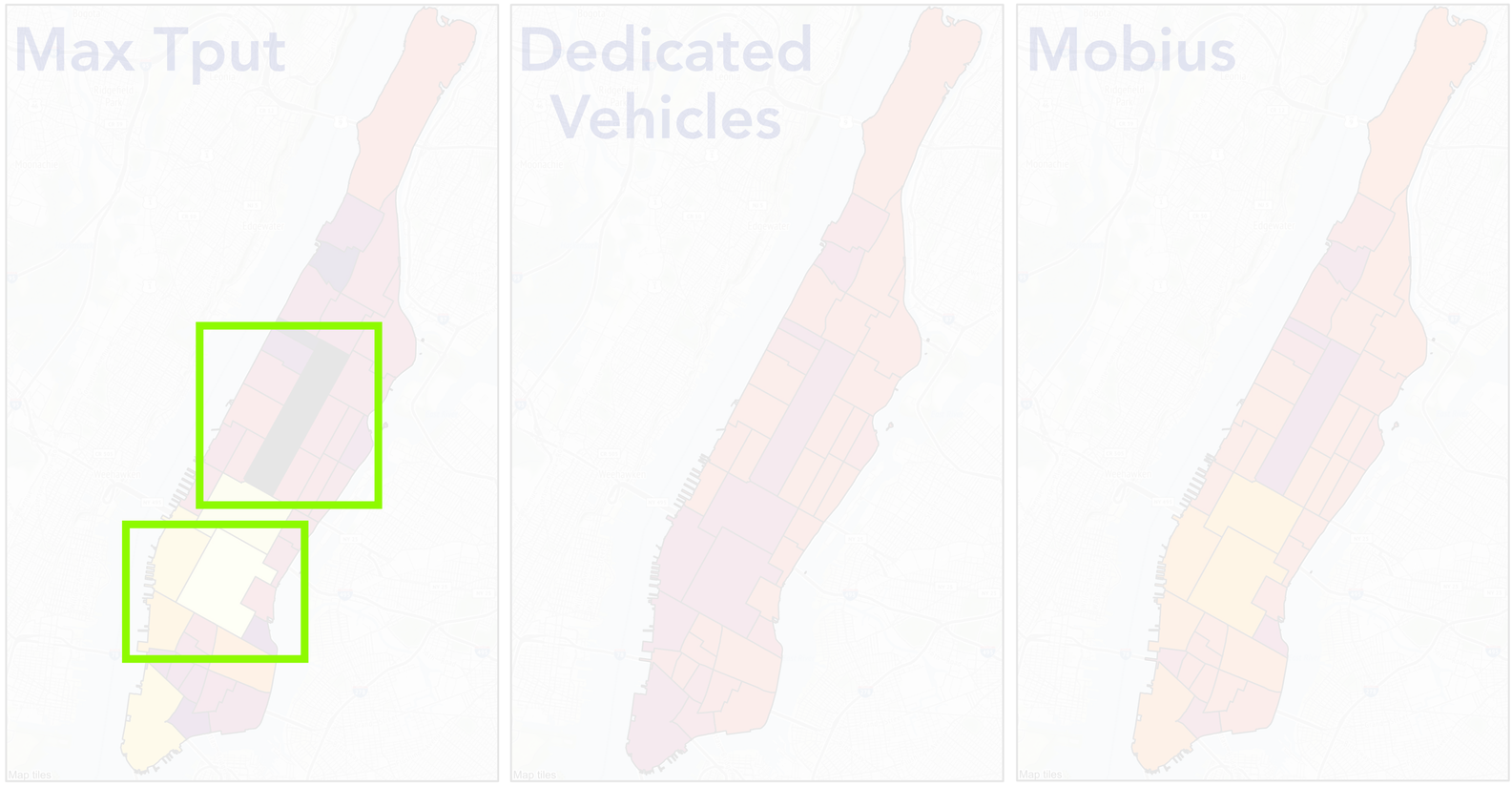

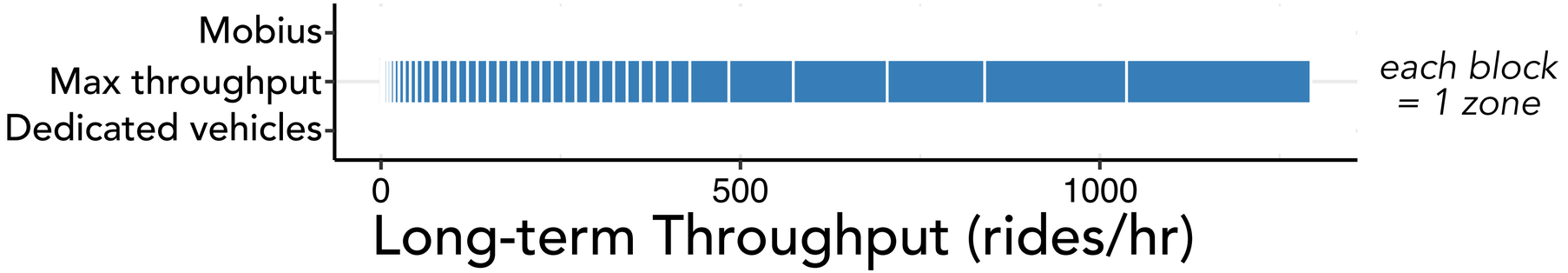

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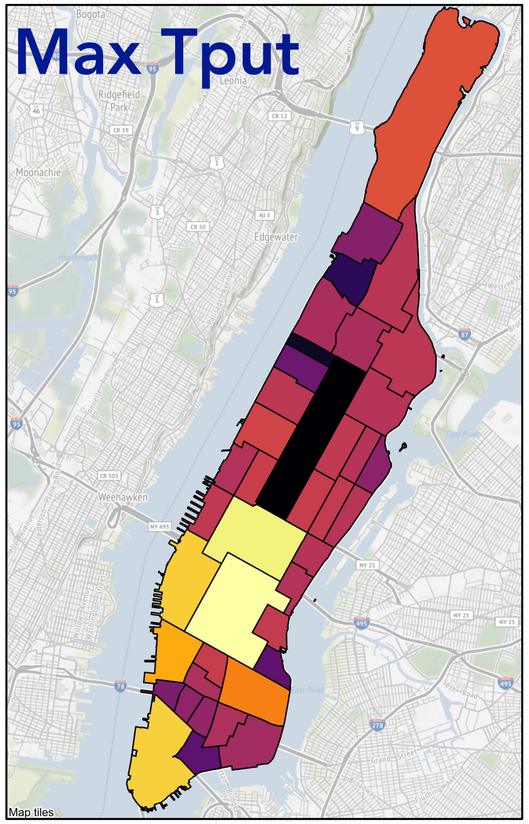

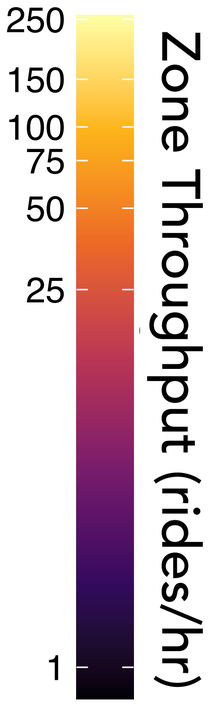

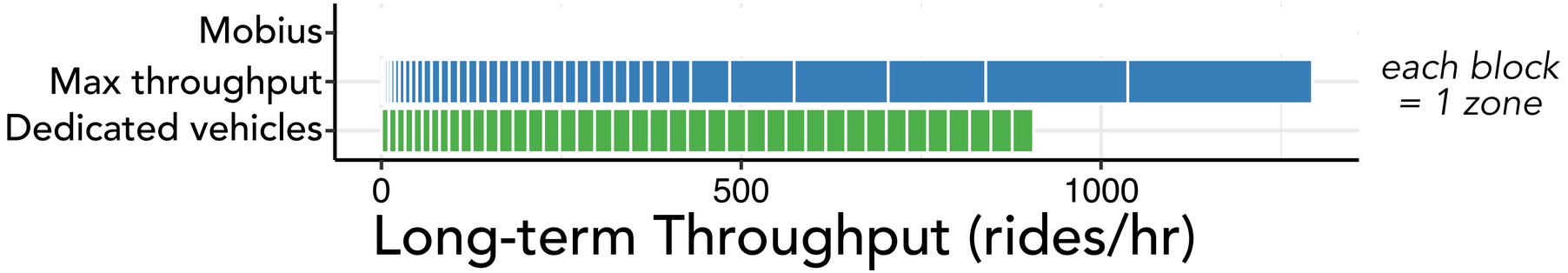

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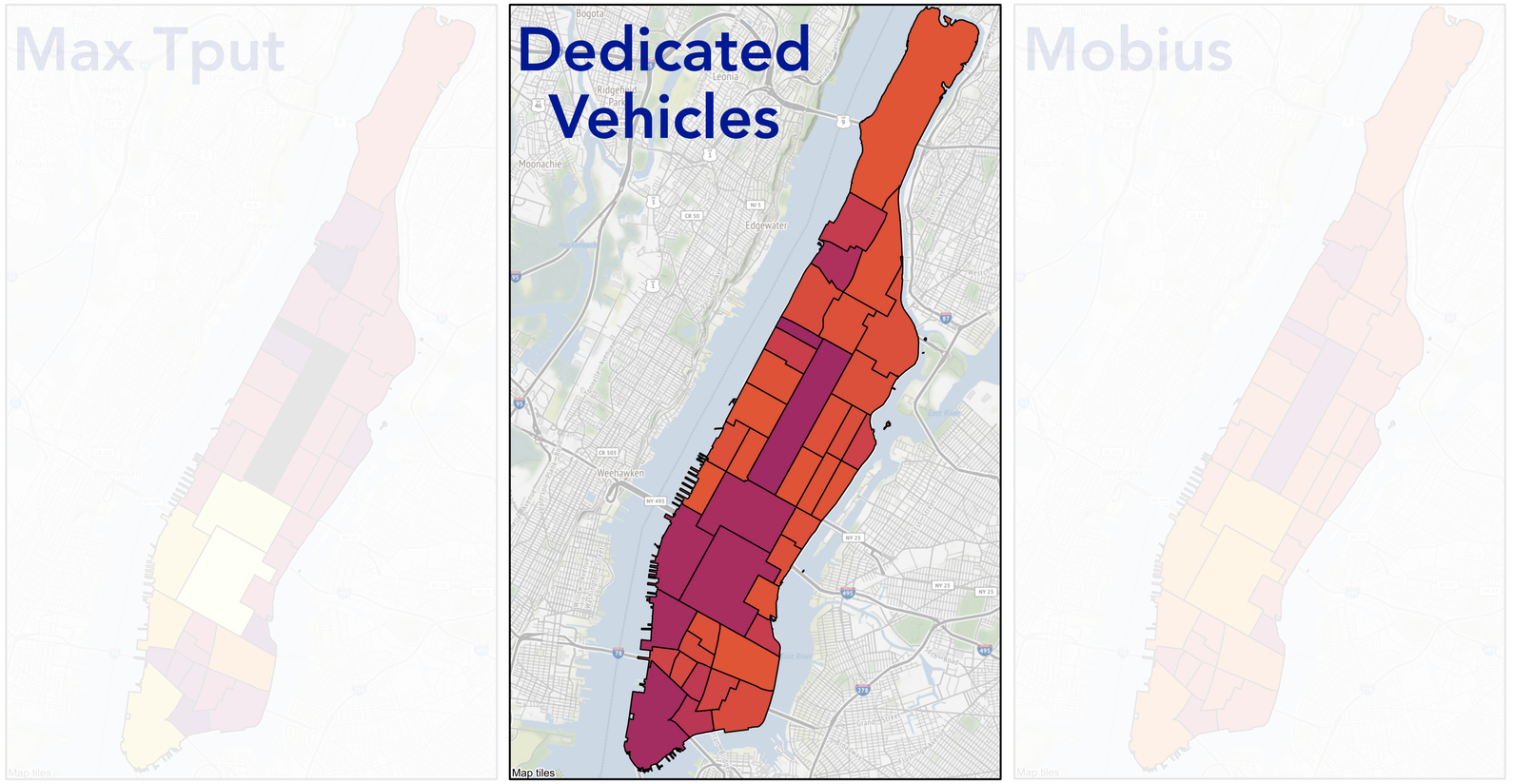

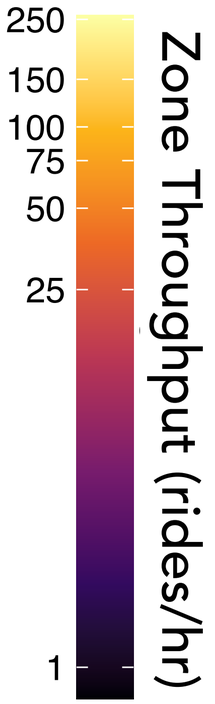

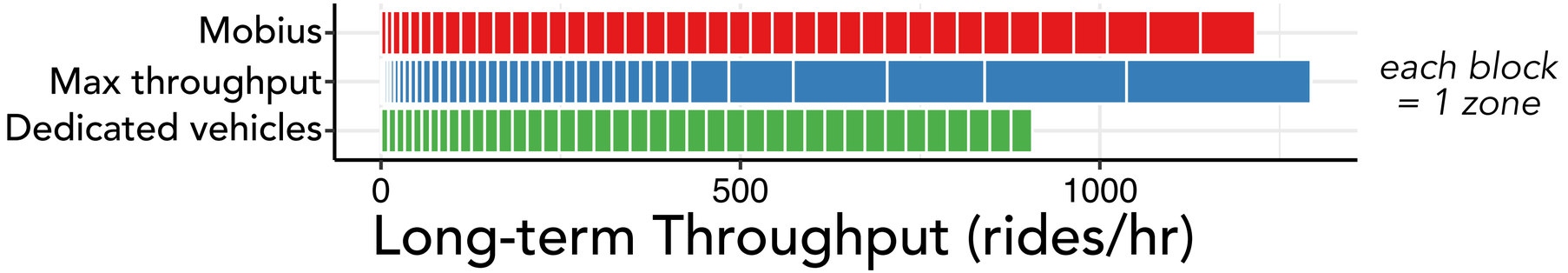

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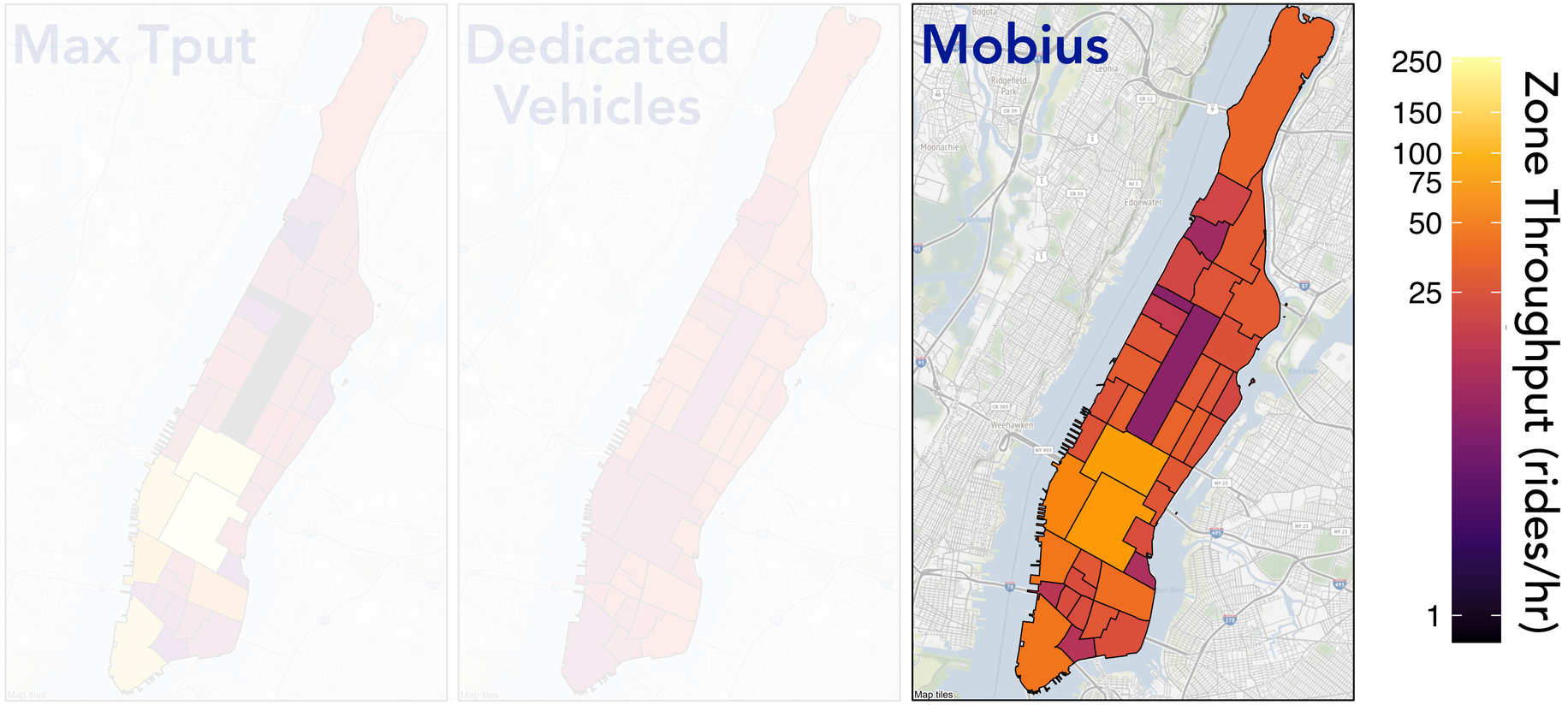
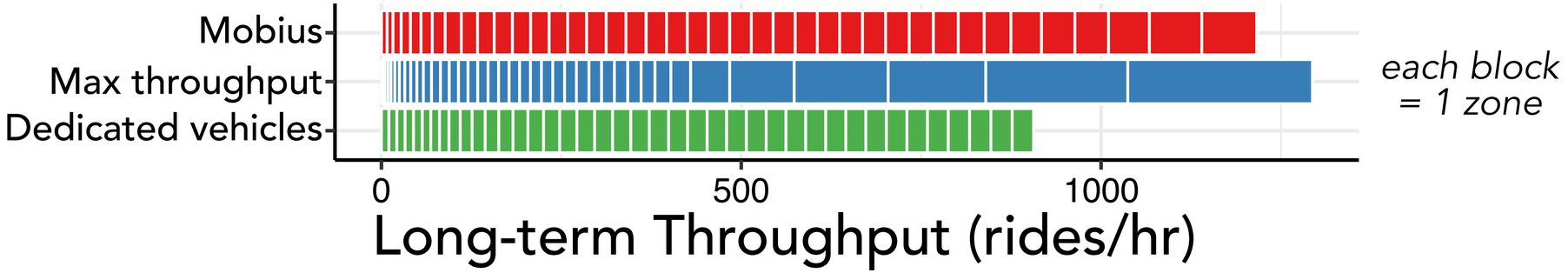
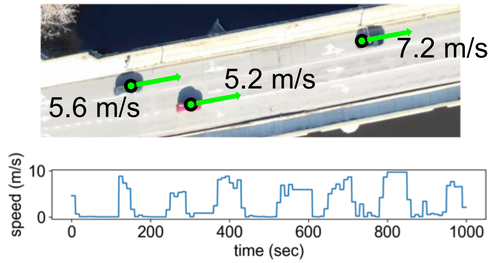
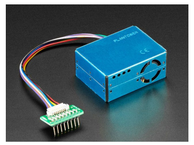
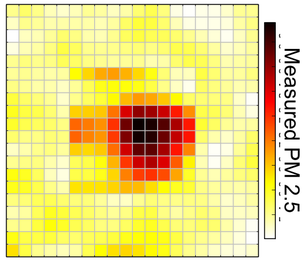
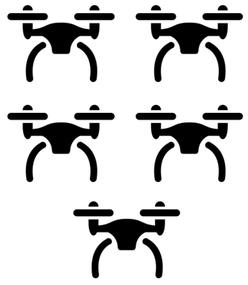


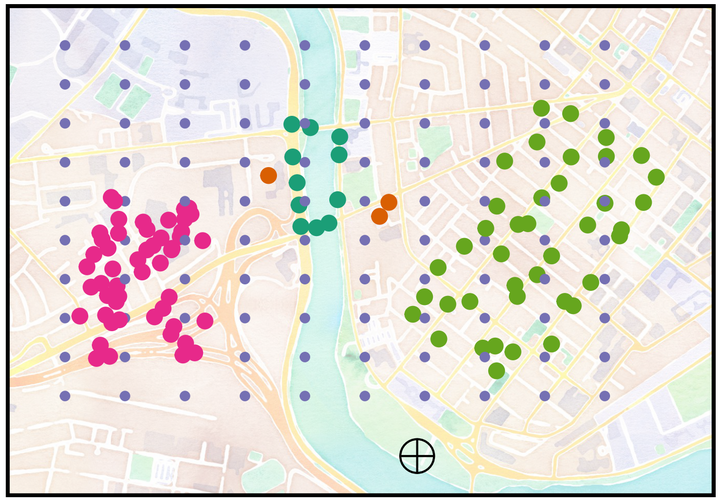


each block = 1 zone

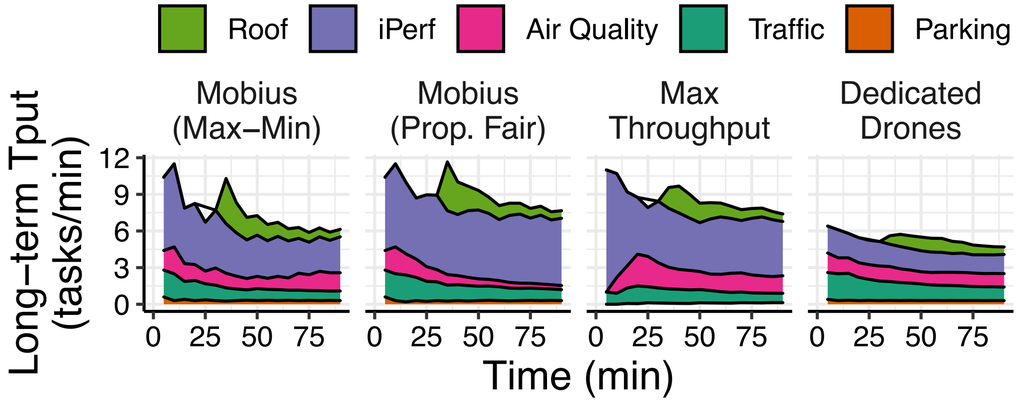
Urban Sensing in Boston

Traffic	Parking	Air Quality	iPerf	Roof
		 PM 2.5 sensor 		
Measure average vehicle speed.	Count occupied spots in parking lot.	Map air quality of plume (AQI).	Profile cellular connectivity.	Image residential roofs.

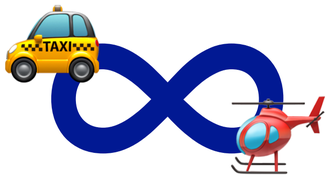




- Recharge
- Traffic
- Parking
- iPerf
- Air Quality
- Roof



Mobius



🌐 mobius.csail.mit.edu

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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