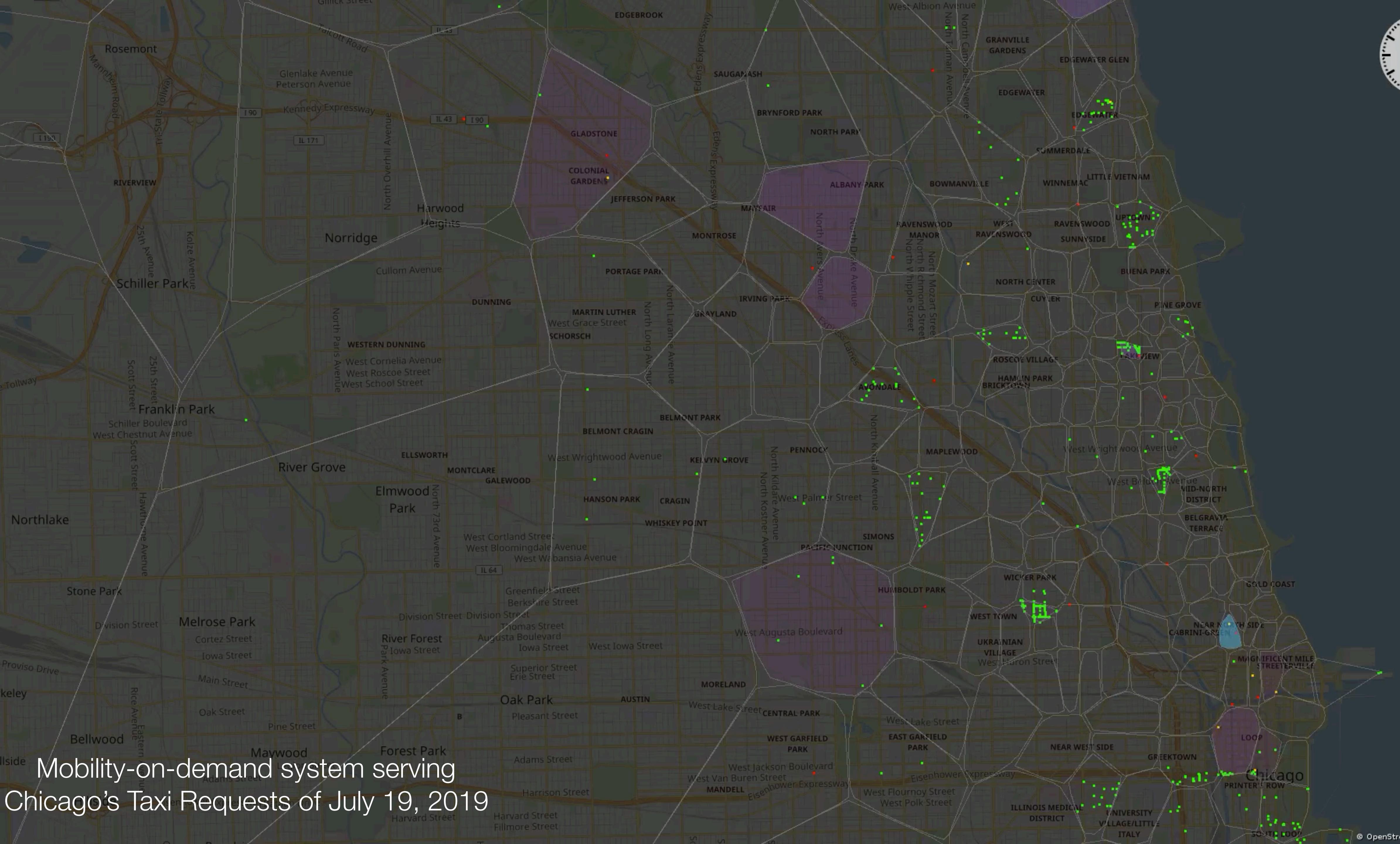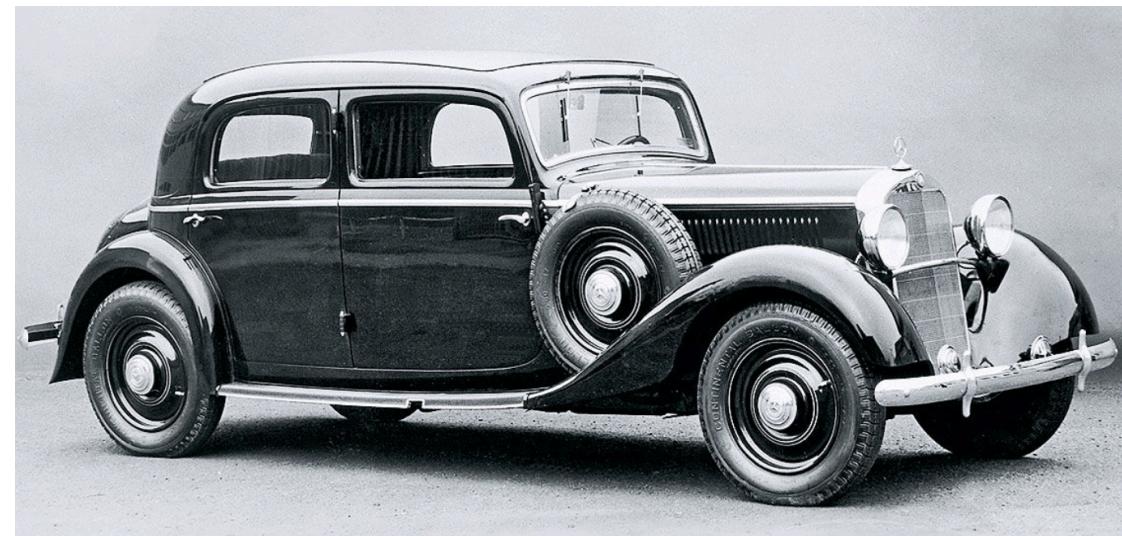# Autonomous Mobility-on-Demand Systems: False Myths and Open Questions

Prof. Dr. Emilio Frazzoli, Claudio Ruch, Jan Hakenberg

Institute for Dynamic Systems and Control
D-MAVT, ETH Zürich, **Switzerland**

Mobility-on-demand system serving
Chicago's Taxi Requests of July 19, 2019

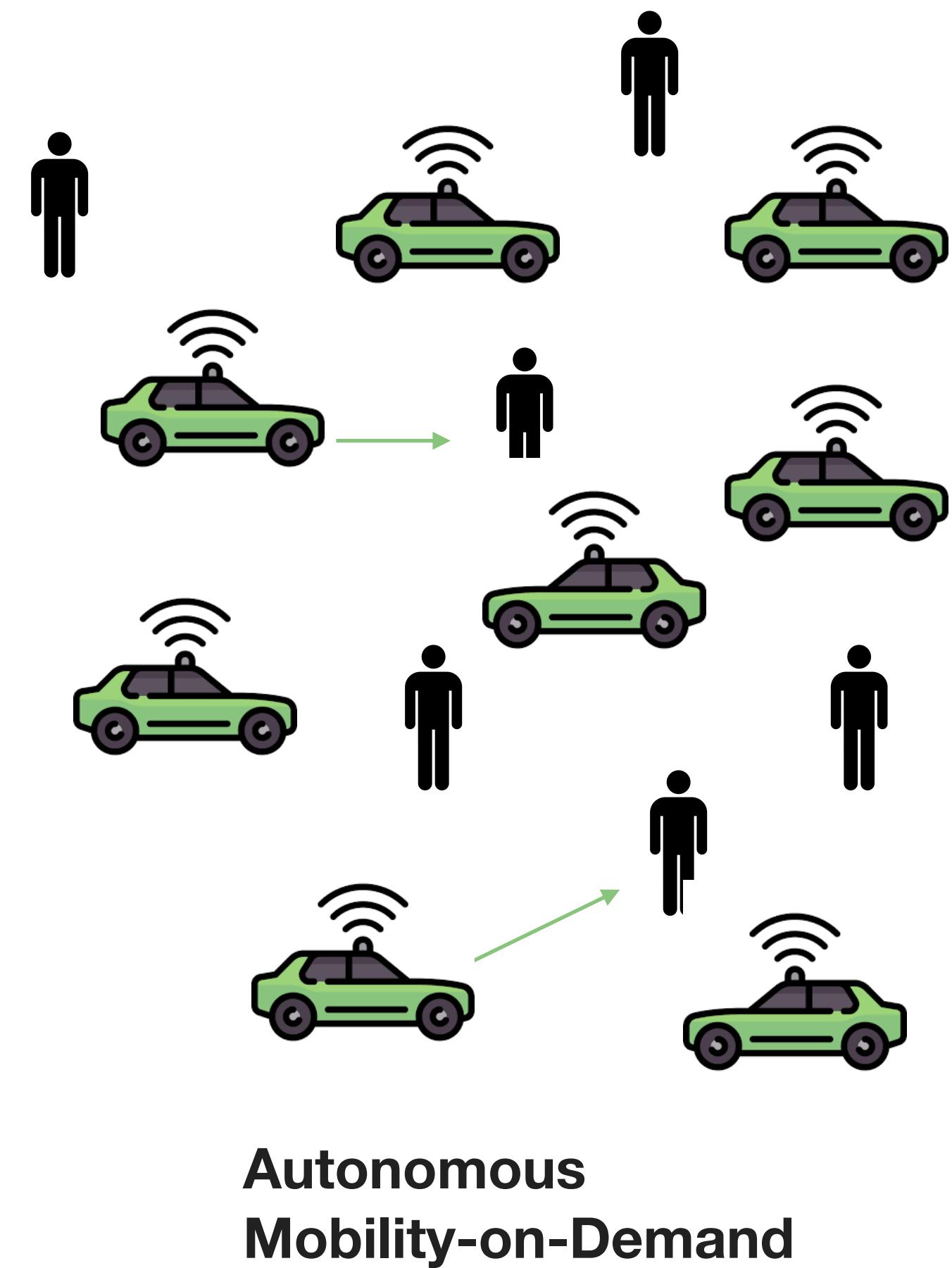# Cars and Autonomous Mobility-on-Demand

Mass-produced car:

**Mobility:
faster than a horse**

Car as consumer product:

Mobility, lifestyle and status
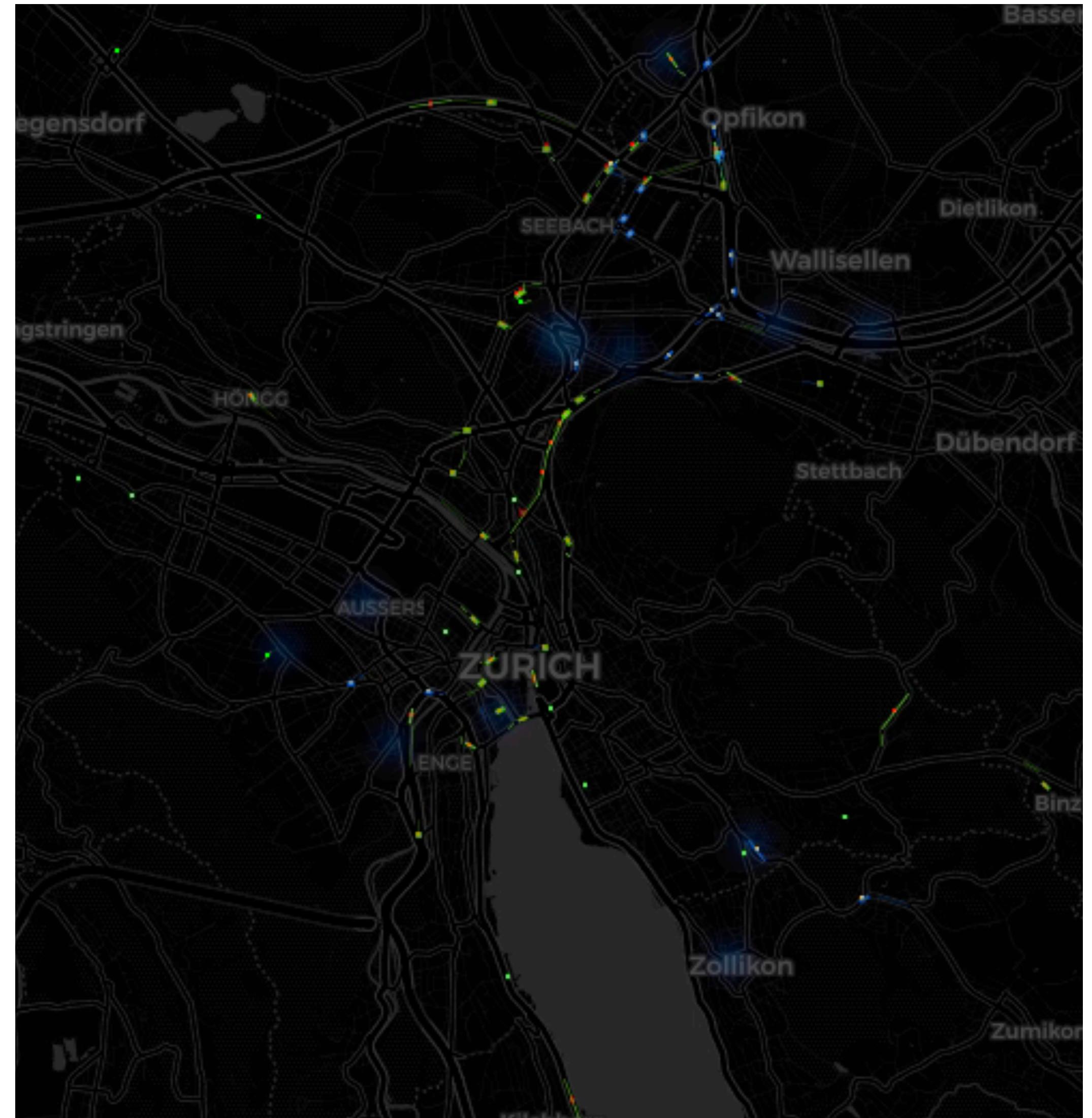
Car without a driver:

Enabling shared cars

**Autonomous
Mobility-on-Demand**

▷ What effects will Autonomous Mobility-on-Demand have on our cities?

▷ What do we know and what do will still not know?

False Myth: AMoD will be a privilege for the wealthy

Simulation Assessment:

- **8 million people** with travel plans from "Microcensus Mobility and Transport"

- **137,000** entering, leaving or staying within the study area (Downtown Zurich)
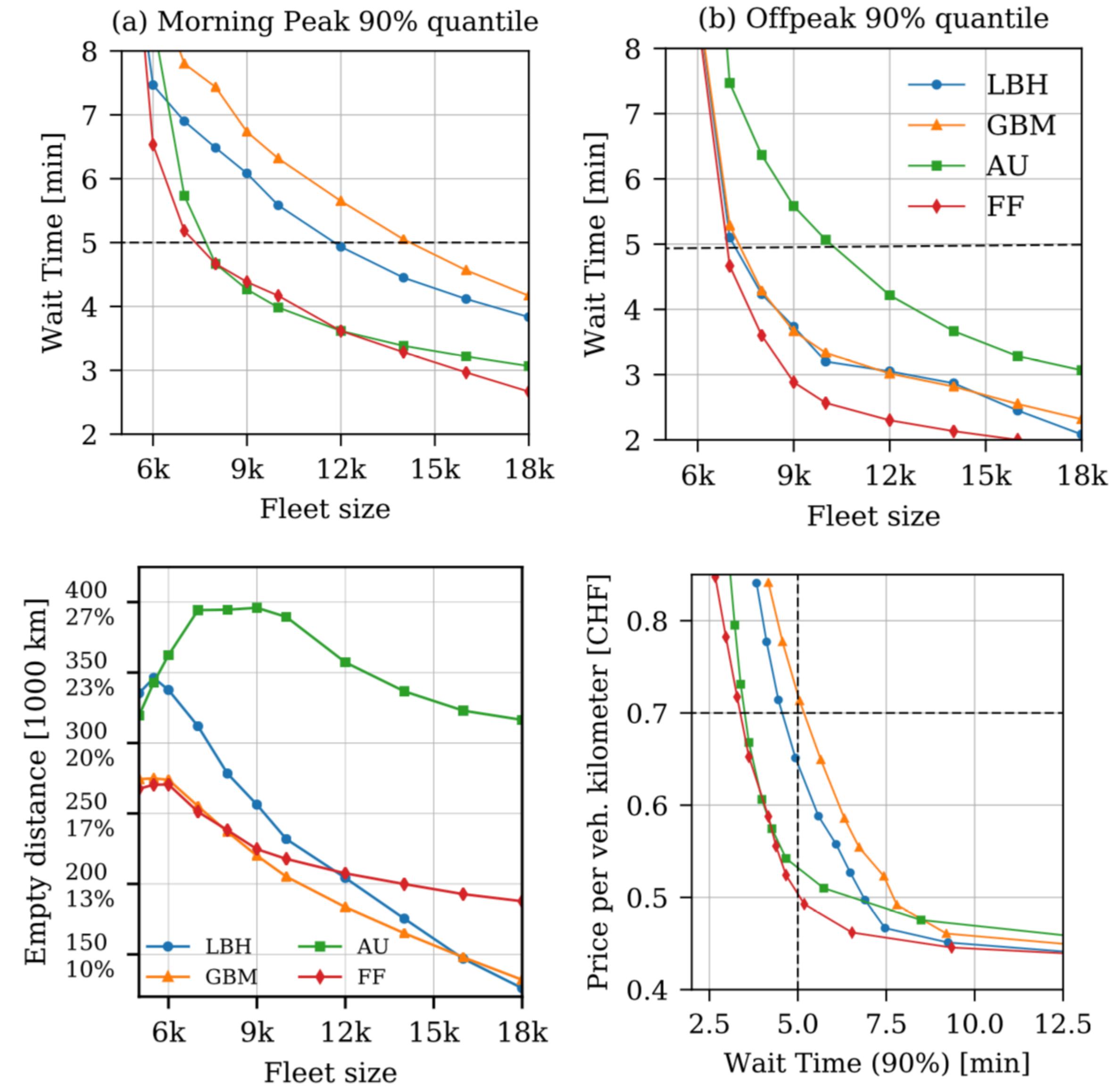
- **363,503** trips to be served by autonomous taxis.

Source: "Hörl, Sebastian, et al. "Fleet operational policies for automated mobility:
A simulation assessment for Zurich." Transportation Research Part C:
Emerging Technologies 102 (2019): 20-31.."

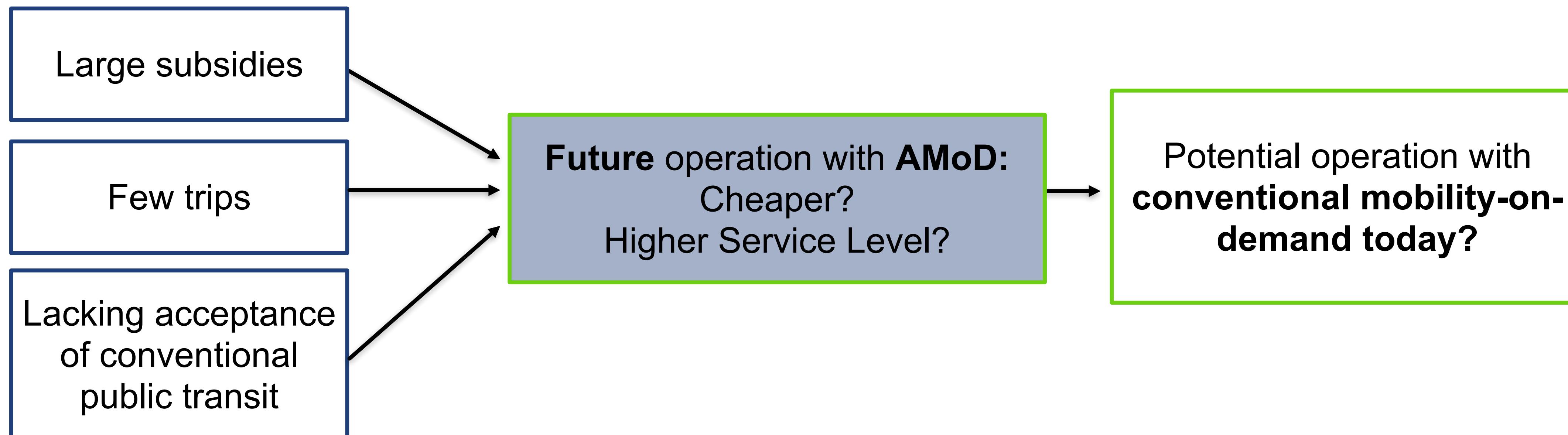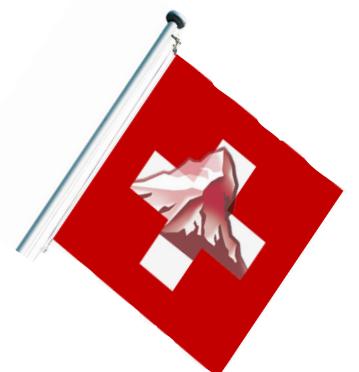# False Myth: AMoD will be a privilege for the wealthy

Results:

- 5 minutes 90%-quantile wait time: between 7,000 and 14,000 vehicles

- Greatly varying for different strategies:

  - empty vehicle miles traveled

  - price / km for certain service level

- Highly competitive with all other modes of transportation at 0.7 USD / km
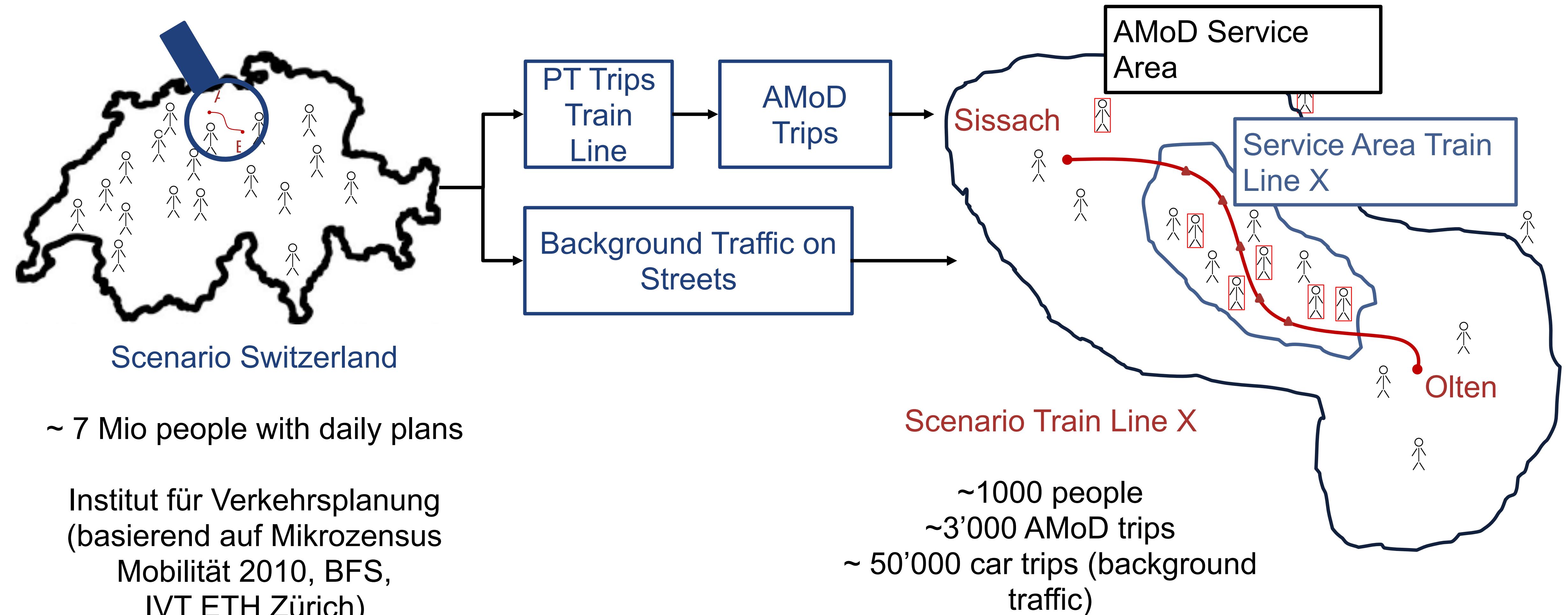
False Myth: AMoD is only good for urban mobility

- Some train lines in Switzerland: **less than 25%** of revenues from ticket and subscription sales.

- Attempts to close down unsuccessful as population considers bus lines inferior and Switzerland is a democracy with strong possibilities of influence for citizens.

```
┌─────────────────┐
│  Large subsidies │ ──────┐
└─────────────────┘        │
                           ▼
┌─────────────────┐   ┌──────────────────────┐      ┌──────────────────────┐
│    Few trips     │ ─▶│ Future operation with │ ───▶ │ Potential operation  │
└─────────────────┘   │    AMoD: Cheaper?     │      │ with conventional     │
                      │ Higher Service Level? │      │ mobility-on-demand    │
┌─────────────────┐   └──────────────────────┘      │ today?                │
│ Lacking acceptance│ ─┘                             └──────────────────────┘
│  of conventional  │
│  public transit   │
└─────────────────┘
```

False Myth: AMoD is only good for urban mobility

Scenario Switzerland

~ 7 Mio people with daily plans

Institut für Verkehrsplanung
(basierend auf Mikrozensus
Mobilität 2010, BFS,
IVT ETH Zürich)

PT Trips Train Line → AMoD Trips →

Background Traffic on Streets →

AMoD Service Area

Sissach

Service Area Train Line X

Olten

Scenario Train Line X

~1000 people
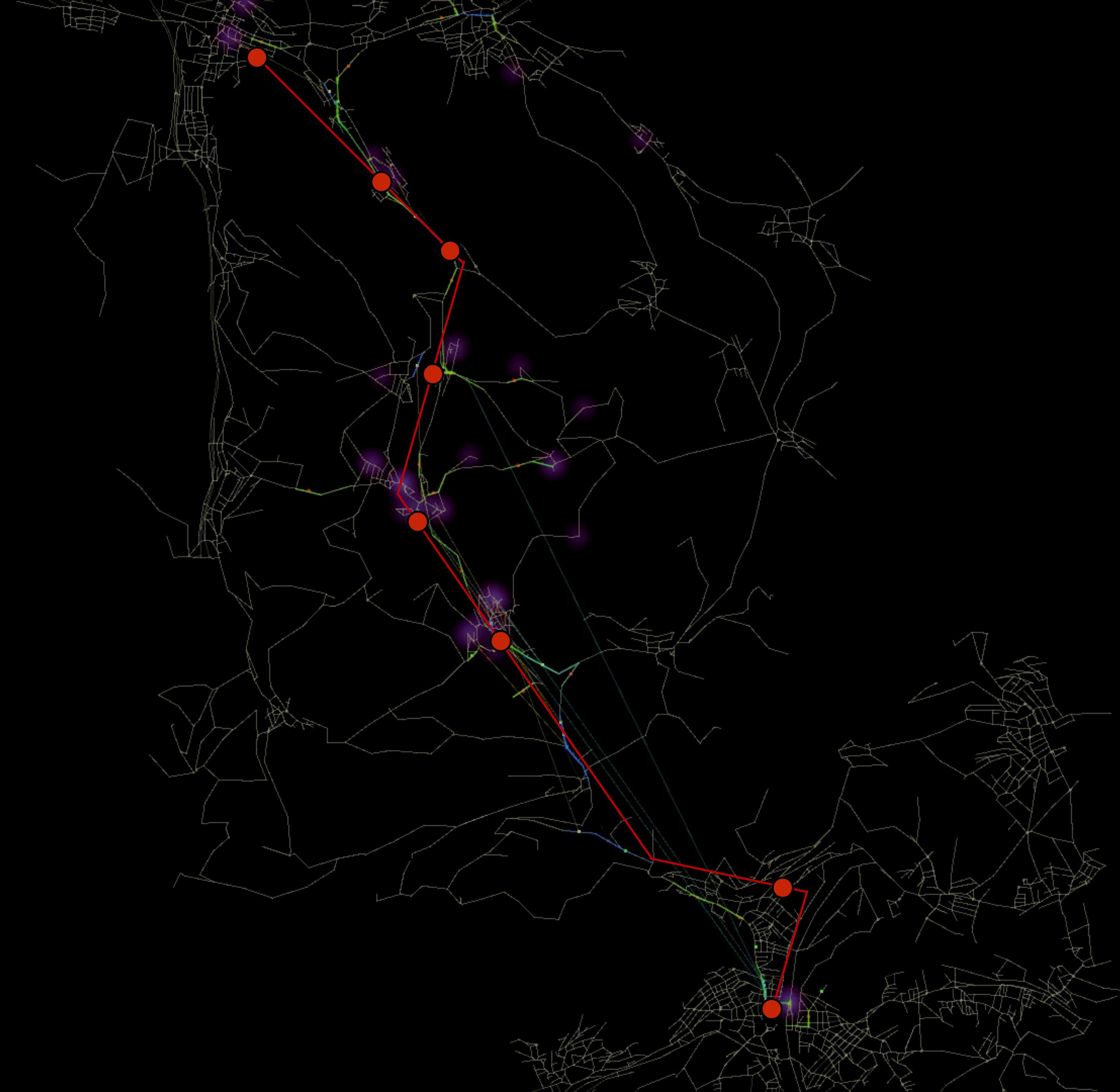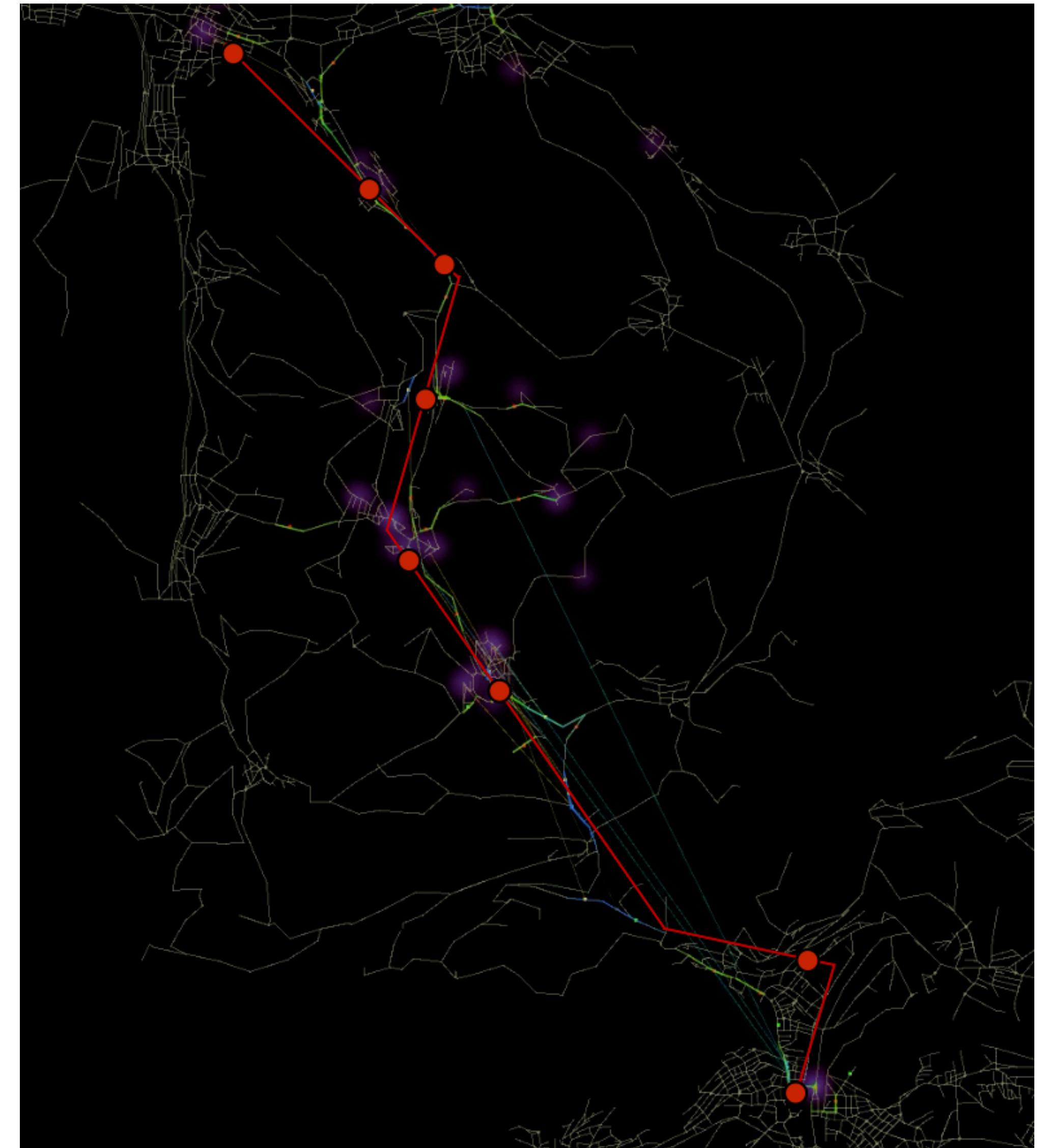~3'000 AMoD trips
~ 50'000 car trips (background traffic)

Source: Sieber, Lukas, Ruch, Claudio et al. "Autonomous mobility-on-demand providing superior public transportation in rural areas." Under Review

i=0   07:16:30

30 with customer
10 pickup
3 rebalance
8 stay
0 off service
47 total

40 open requests
27 maxWaitTime [min]
138 matched req.

8161/ 9049 streets

13 zoom
13 m/pixel

False Myth: AMoD is only good for urban mobility

		Thunersee	Boncourt	Homburgertal	Tösstal
Passengers per day P		416	590	1000	8300
Length [km]		18	11	18	42
Number Taxis N *		17	22	47	825
Share Ratio P/N		26	26.8	21.3	10.1
Average Journey Time [min]	Train	25.2	26.0	24.8	30.5
	MoD	14.5	14.7	18.1	22.6
Annual operational Costs [Mio CHF]	Train Line	3.8	2.4	3.8	12.2
	Autonomous MoD	0.65	0.89	1.72	23.3
	Conventional MoD	2.17	3.14	6.54	79.6

False Myth: Efficient AMoD requires multi-party ride sharing

Simulation Assessment:

- Travel demand of **train line** "Homburgertal"

- Unit-capacity policy:
  Global Bipartite Matching

- Ride-sharing policy: (best in literature)
  High Capacity Shared Autonomous Mobility-
  on-Demand Algorithm (HCRS)

- Efficiency gains:
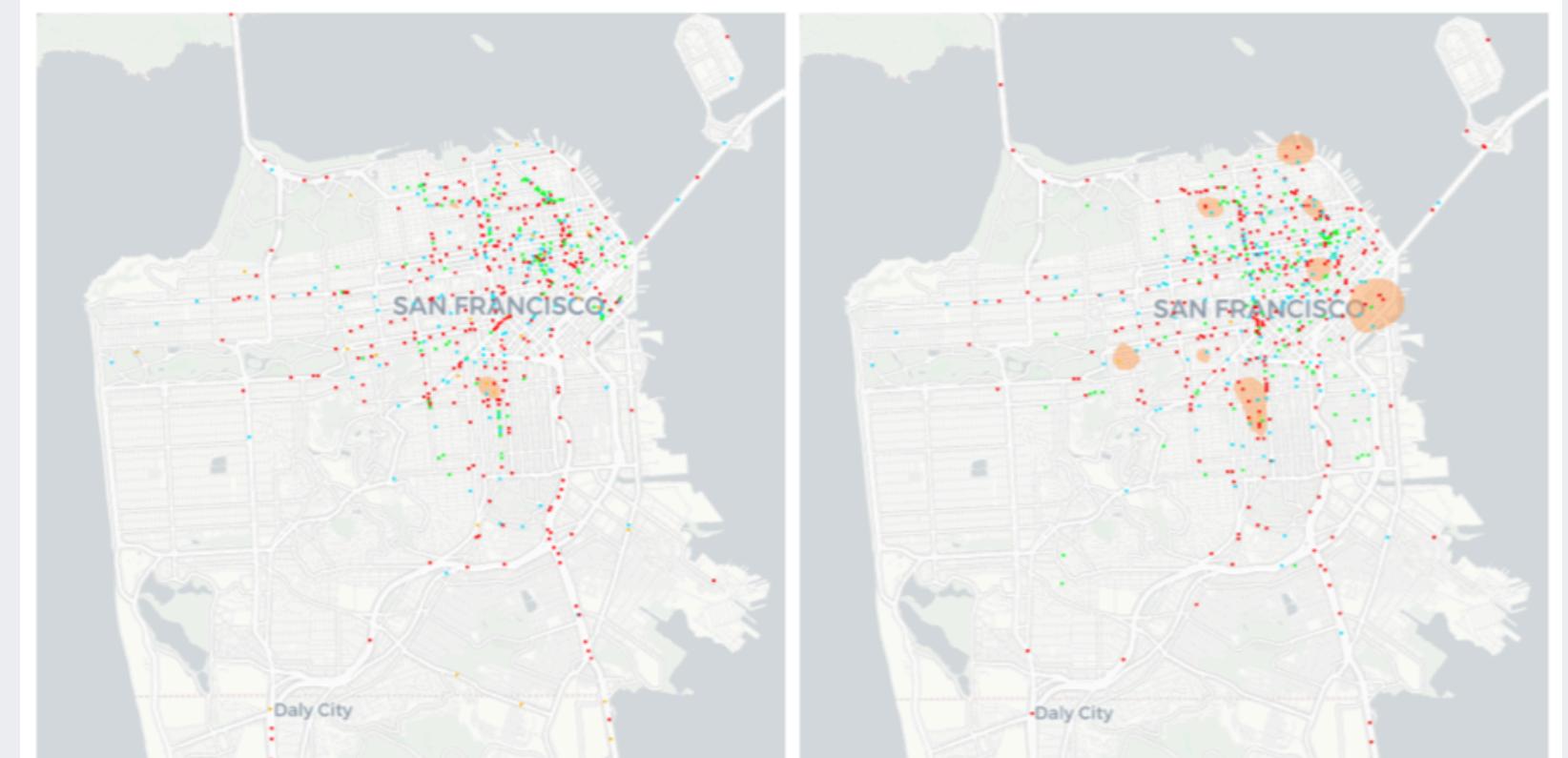 29% reduction in fleet size, 12% less VMT for
  3% more total travel time

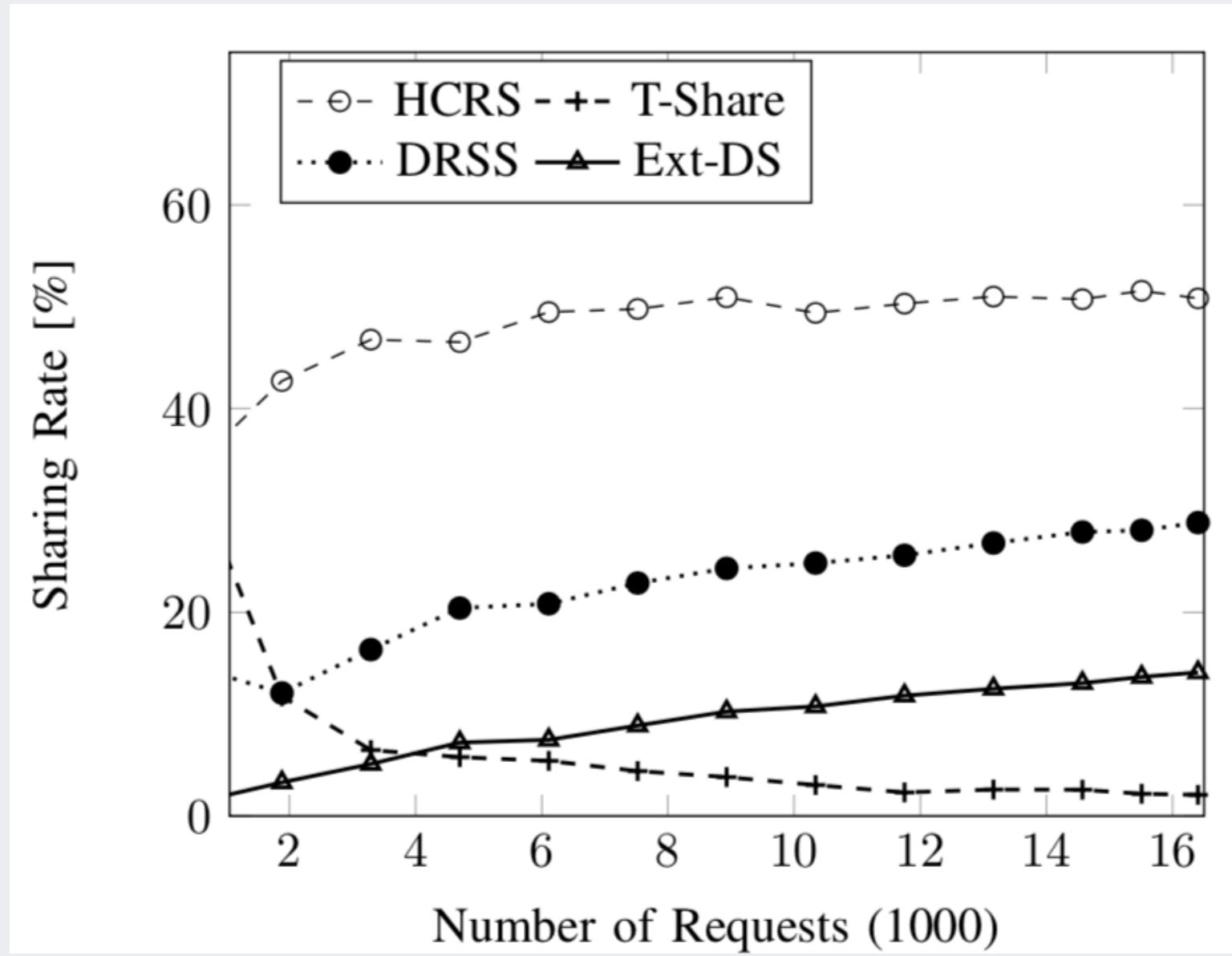| Operational Policy	Fleet Size	Vehicle Miles Traveled	Mean Total Travel Time
1MoD (GBM)	35	6,447 miles	12:31 min
RMoD (HCRS)	35	5,637 miles	12:12 min
RMoD (HCRS)	25	5,649 miles	12:56 min
RMoD (HCRS)	15	5,140 miles	15:58 min
RMoD (HCRS)	10	4,365 miles	23:01 min

False Myth: Efficient AMoD requires multi-party ride sharing

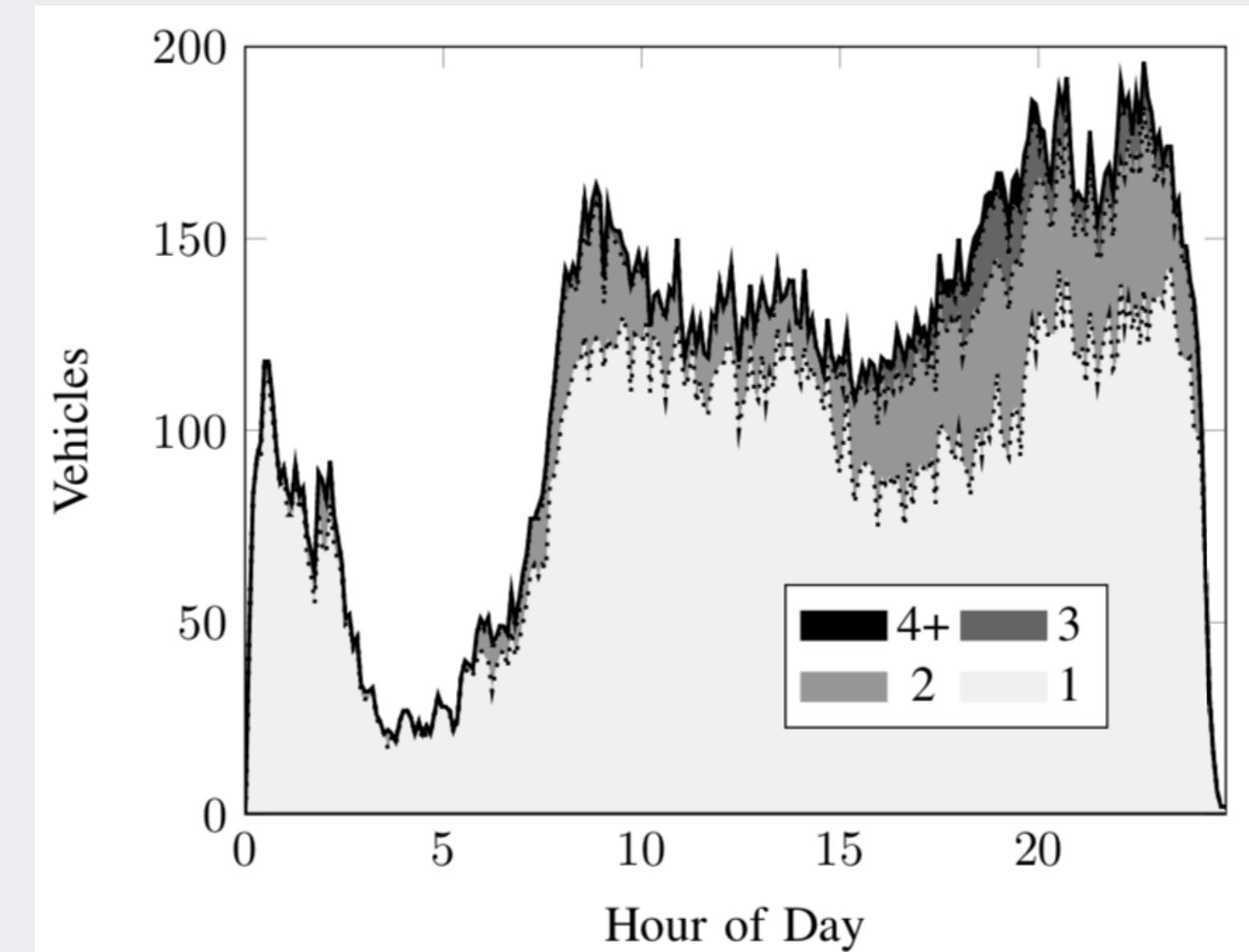Ride-sharing in a densely populated city

- San Francisco taxi demand

- Similar efficiency gains:
  29% reduction in fleet size,
  10% less VMT for 15% more total travel time

Increasing request density
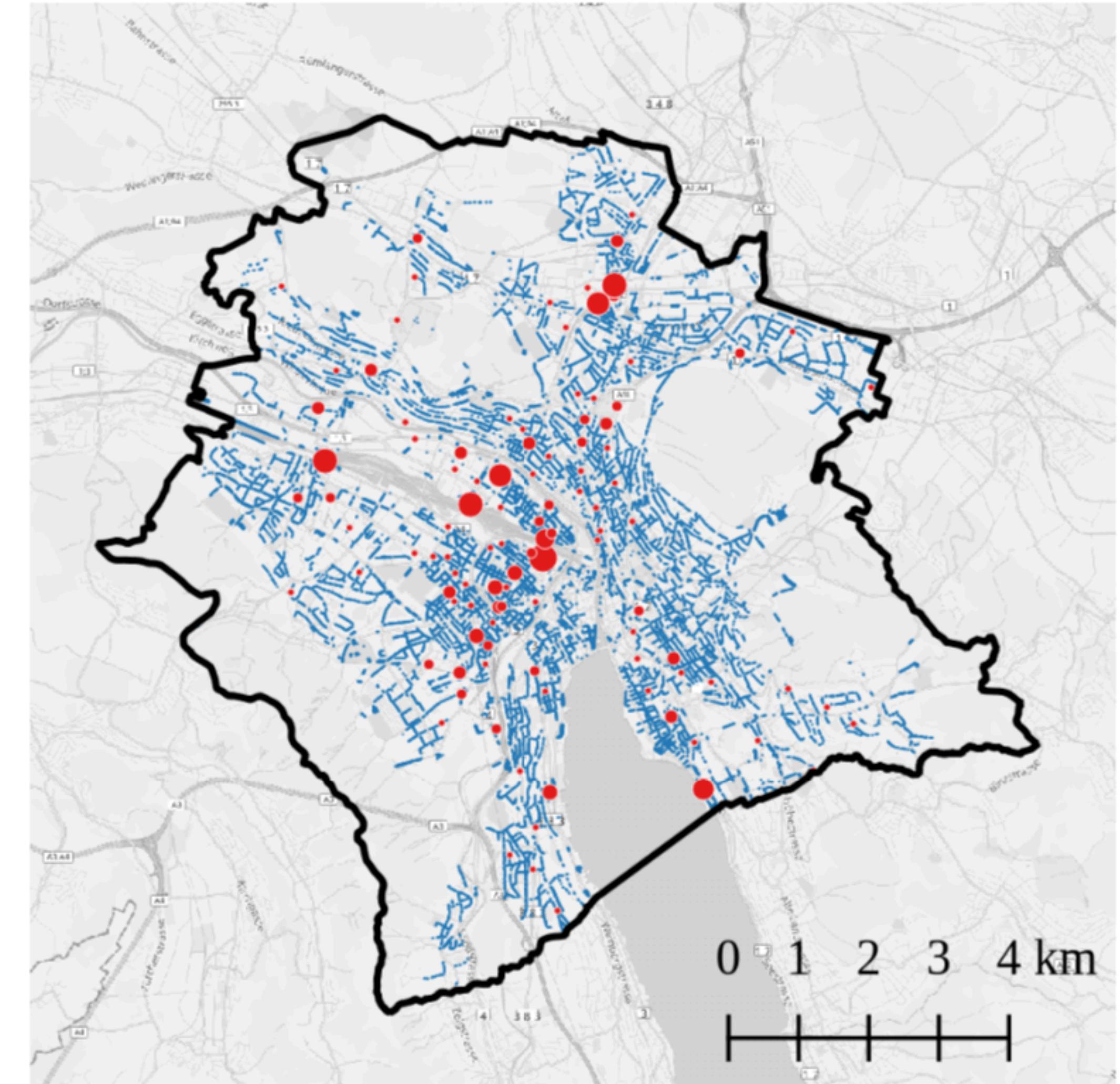→
small increase of sharing rate

Utilization of vehicles
→
hardly more than 2 parties

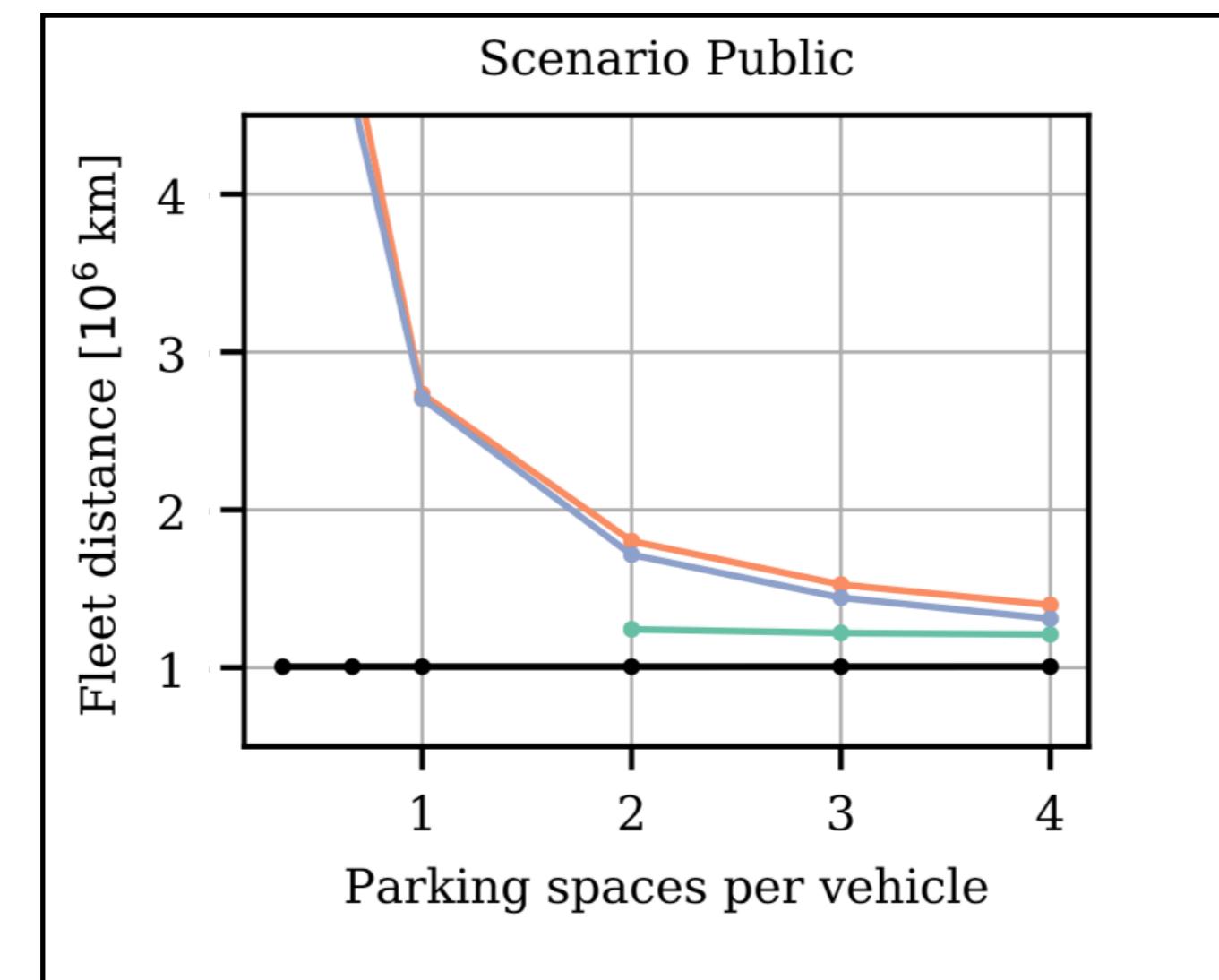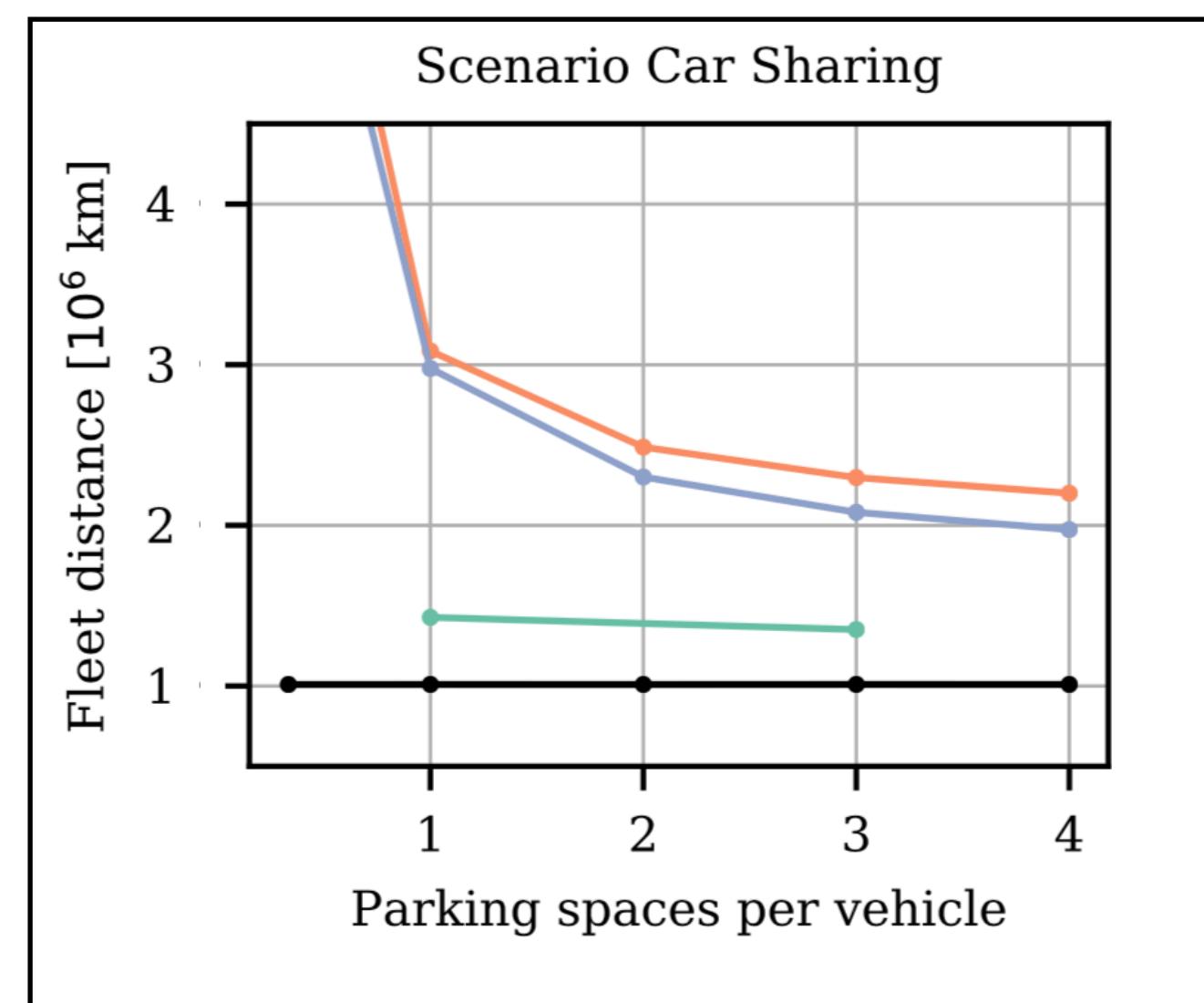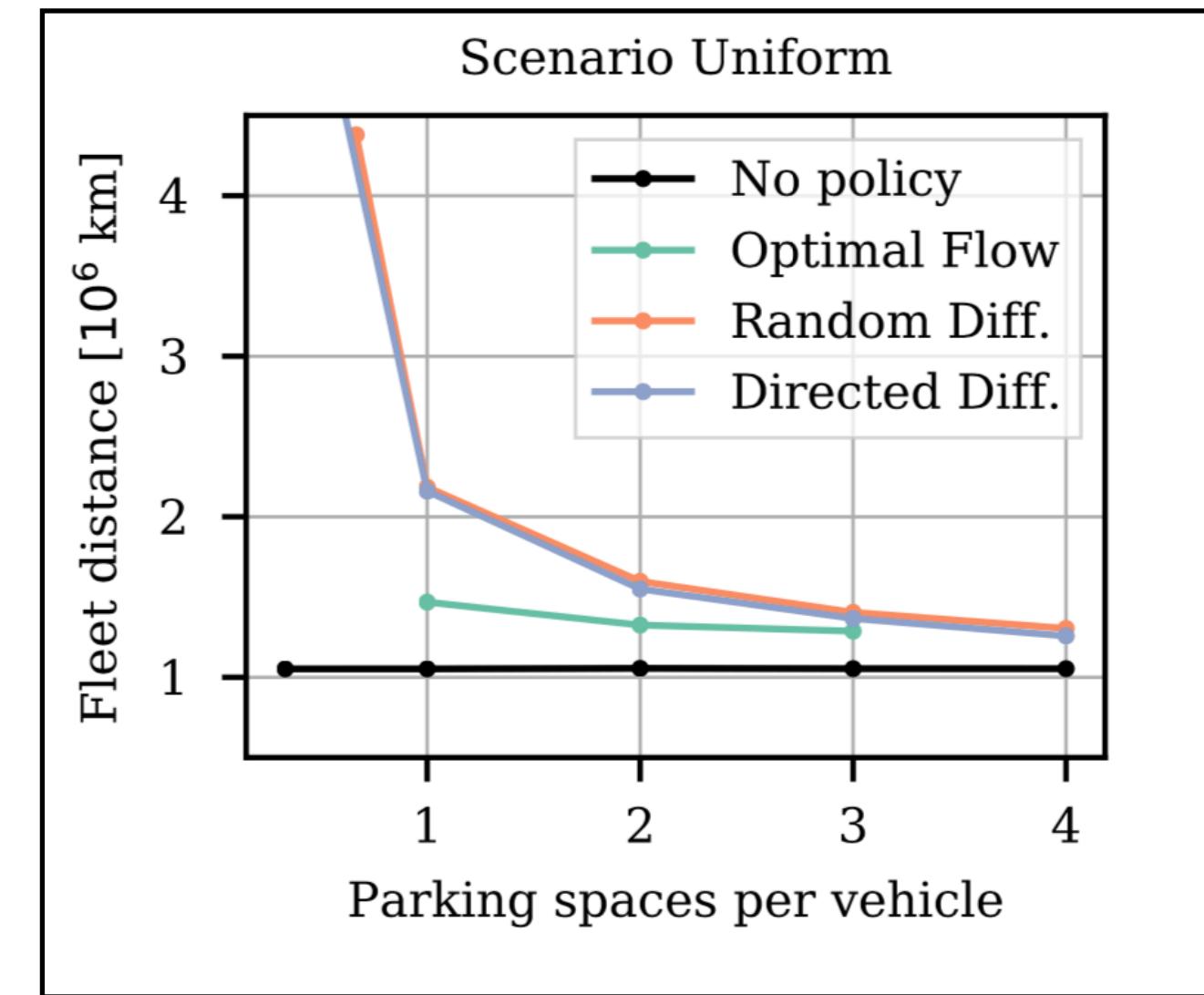# False Myth: AMoD will lead to "zombie cars"

Limited parking spaces:

- Idle and staying vehicles must park in a lot.

- Parking capacity violation is tracked.

- Different **parking operating policies** ensure minimization of parking capacity violations.

- Parking spaces are distributed…

  1. uniformly, randomly

  2. as public parking spaces

  3. as 2-way car-sharing scheme Mobility™

Source: Ruch, Claudio et al. "How Many Parking Spaces
Does a Mobility-on-Demand System Require? " Under Review

False Myth: AMoD will lead to "zombie cars"

Results:

- 1 space per vehicle →
  no parking capacity violations

- Policies with access to local
  information (cruising search)
  → excess VMT
  → work best for uniform distribution

- Policies with global information and
  fleet coordination
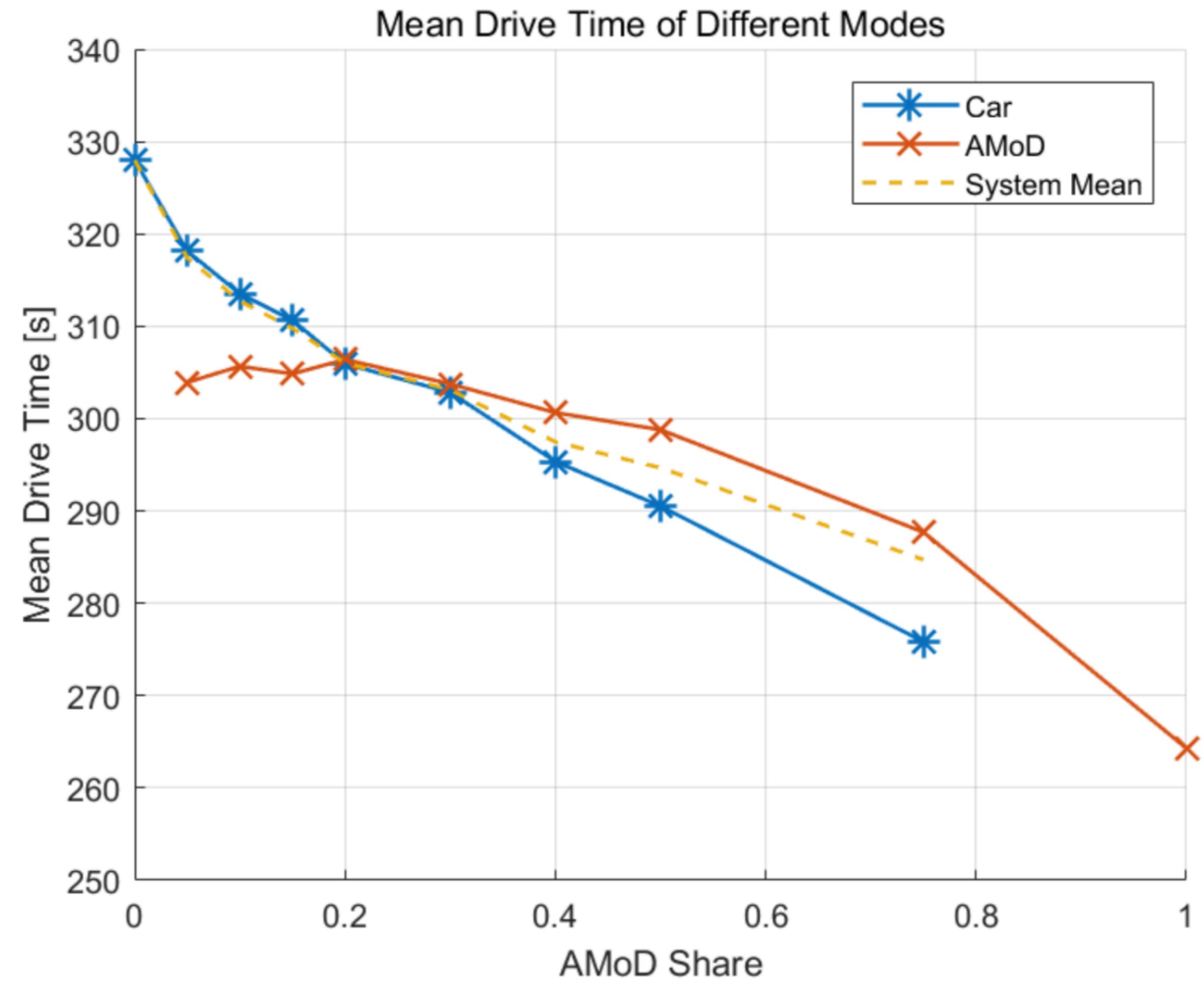 → little additional VMT
  → work for most distributions

False Myth: AMoD will increase congestion

- What is the effect of AMoD on congestion in urban environments? Different factors matter…

- Congestion can be reduced with different elements of fleet operation:

  - Routing
  - Dispatching
  - Rebalancing

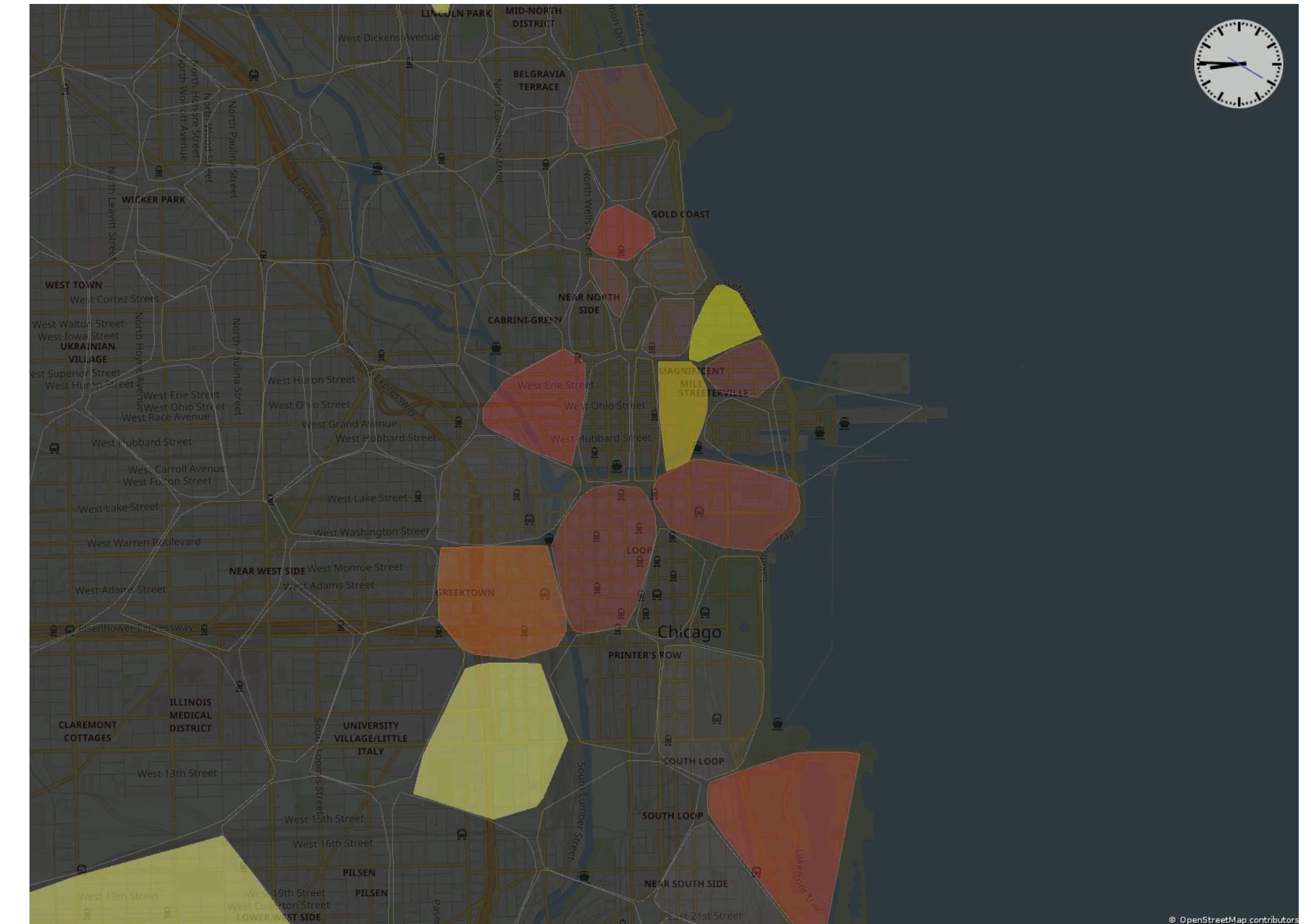|	Private Cars	AMoD
Additional Vehicle Miles Driven	No	Yes (EMD)
Number of Vehicles Active on Road	Lower	Higher
Control of Operations	Limited, Selfish Vehicle Behavior	Large, Coordinated Fleet Operation

False Myth: AMoD will increase congestion

- Literature: AMoD increases congestion, e.g., [Maciejewski et el., Congestion Effects Of Autonomous Taxi Fleets, 2017]

- But: newly developed strategy to reduce congestion in coordinated system:
  - Mean drive time: -19%
  - VMT: +29%
  - 95% quantile wait time: 8:38 min

- Comparison of AMoD and private car travel times raise important questions…

Mean Drive Time of Different Modes

Open question: What is a Fair Behavior?
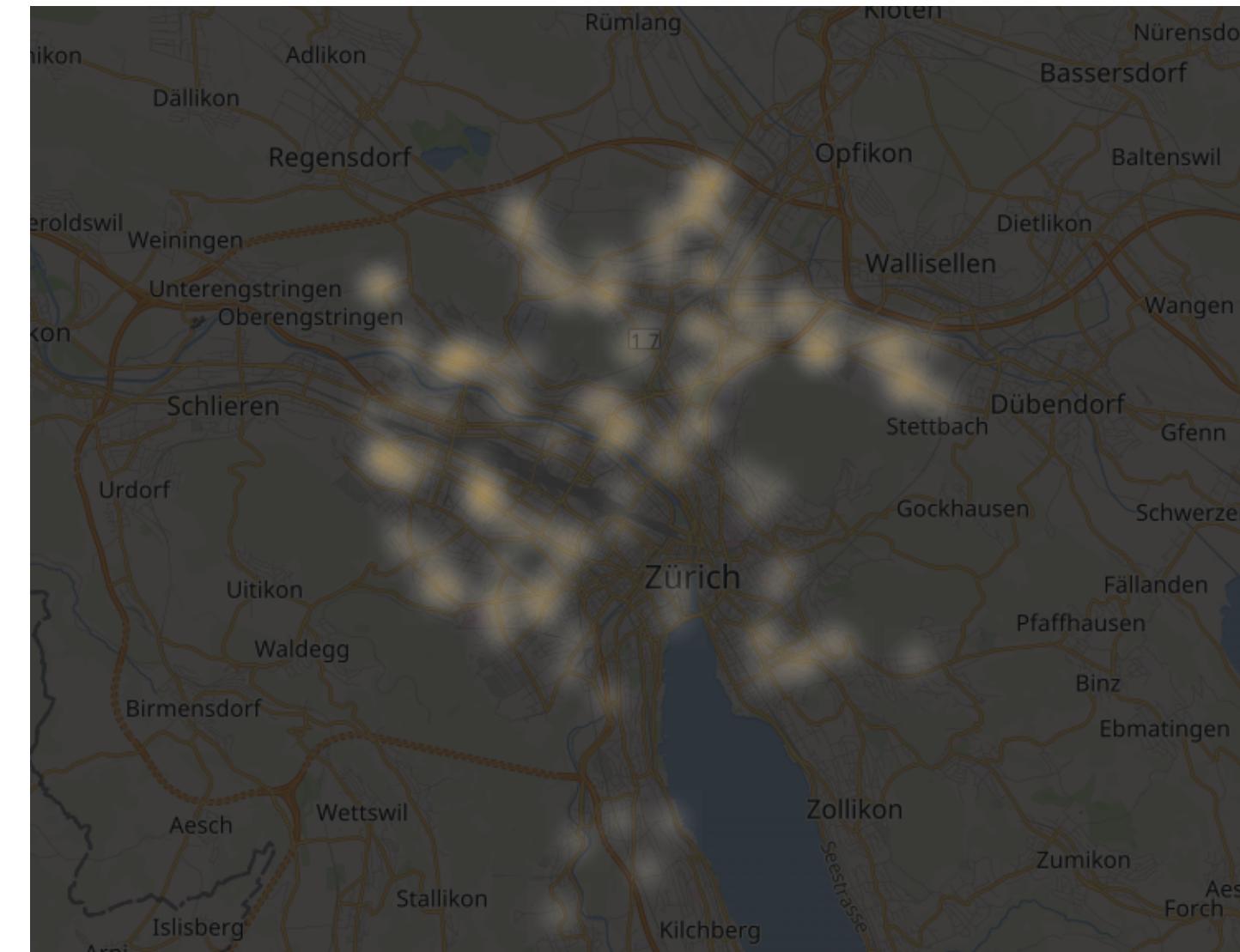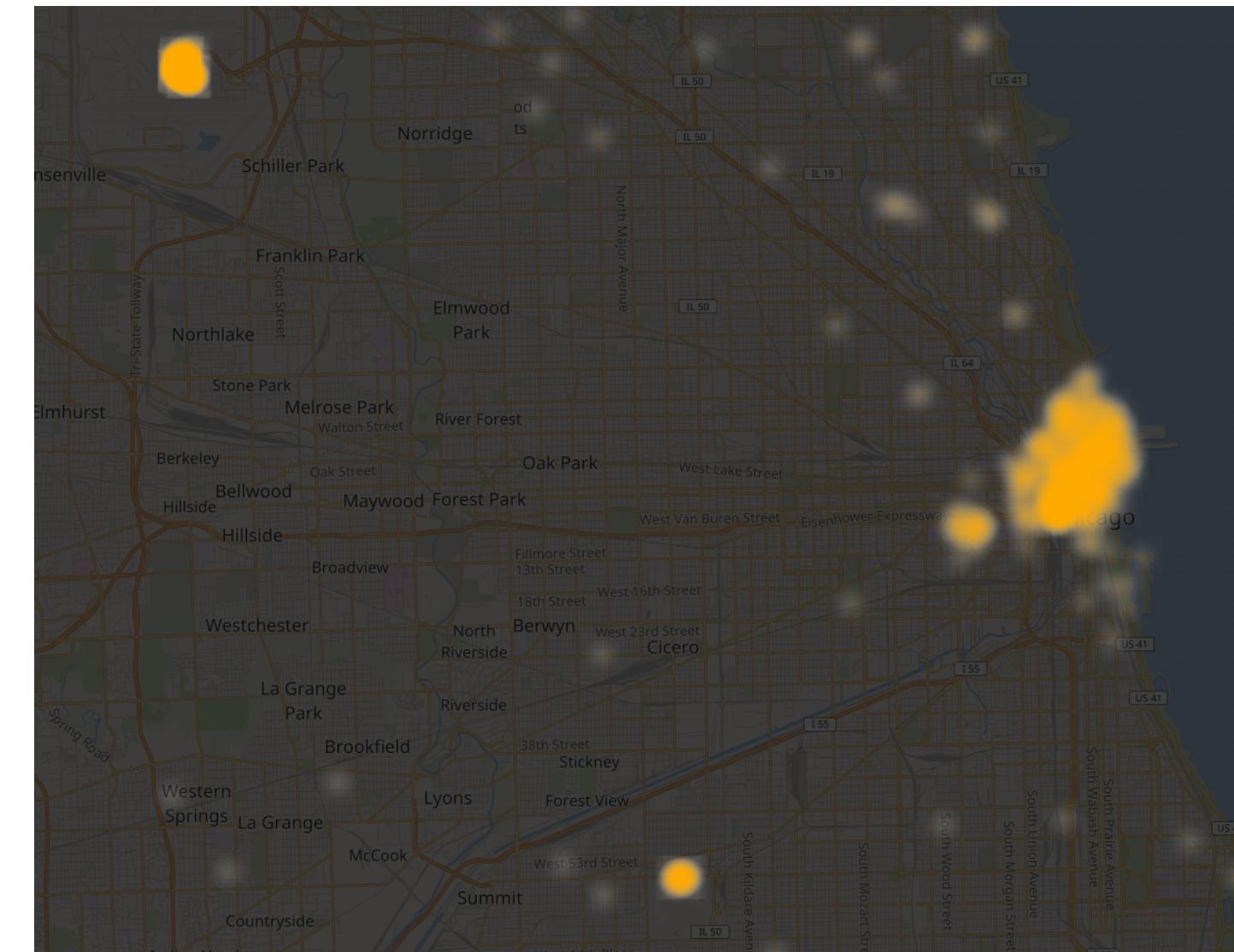
How can we establish fairness
with respect to:

- waiting times?

- travel times?

- trip distributions to operators?

- congestion fees?

- …

Orange heatmap:
median wait time in areas

Open question: What Demand Scenarios Are Best for AMoD?

- When is large-scale on-demand mobility the best option?

  - What request density?

  - What request distribution?

  - …

Orange heatmap:
open requests

Open question: What are the Effects of Induced Demand?

- Short-term behavioural changes:
  "Taking the RoboTaxi instead of the train."

- Mid-term behavioral changes:
  "Selling the car and switching to RoboTaxis and trains"

- Long-term behavioral changes:
  "Moving to a more remote location because the RoboTaxi travel is so convenient.."

Conclusions

- **There are things we now know:**
  Our vision of large-scale mobility-on-demand systems begins to materialize, as ill-informed False Myths are debunked one by one.

- **There are things we don't know:**
  Important aspects remain very unclear.

- **The consequence:**
  Quantitative, in-depth studies of mobility-on-demand systems, AND large-scale operational deployments are still necessary.

▷ **Thank you for your attention!**