

# Broader impact of autonomous vehicles on our cities findings and outlook for future

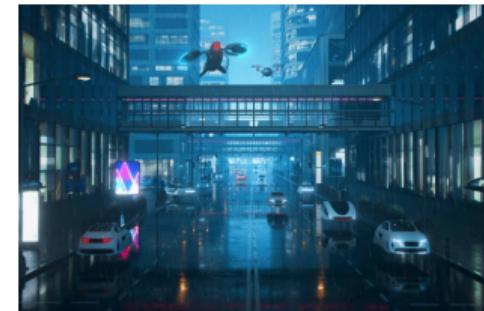
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# Playing Urban Mobility Games With Autonomous Vehicles

## Agenda

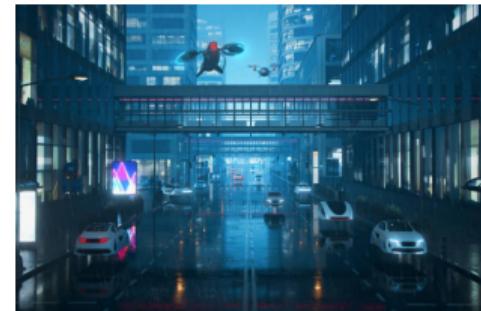
- Autonomous Vehicles AD 2026  
**Waymo and others**
- Research Gap  
**What are we missing?**
- Experimental Polygon  
**Urban Routing Game**
- Findings  
**What we found?**
- Insights  
**What's next?**



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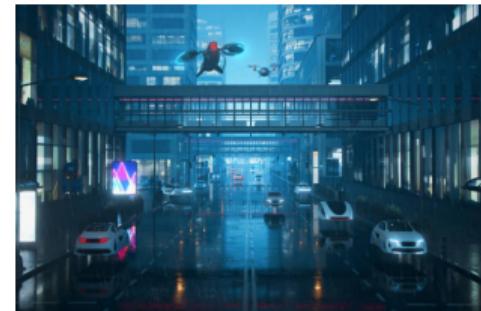
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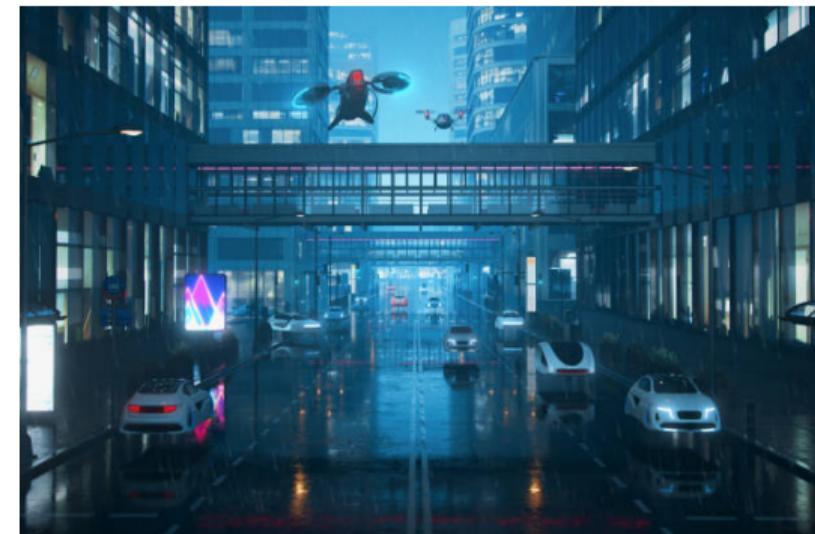
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# Future(s) of urban mobility



low-tech, fewer cars

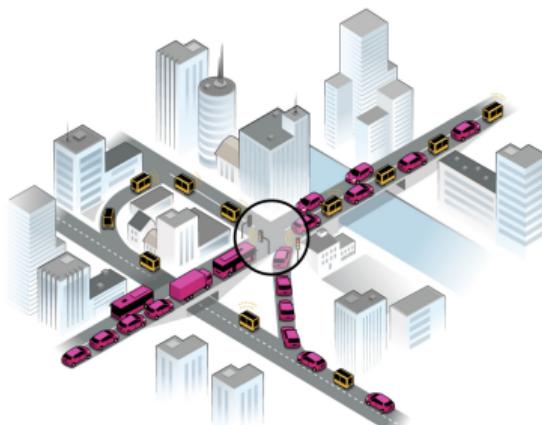


high-tech, more cars



European Research Council  
Funding for the European Union's

Autonomous Vehicles AD 2026 - where we are?



# Connected autonomous vehicles

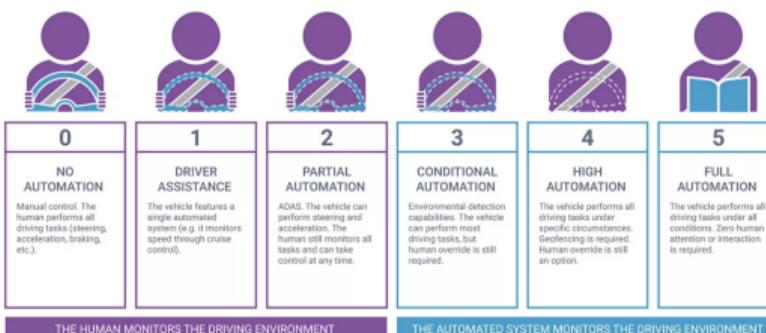
## CAVs

### Autonomous car

a car that is capable of travelling without human input

### SYNOPSIS\*

#### LEVELS OF DRIVING AUTOMATION



# Autonomous Vehicles AD 2026

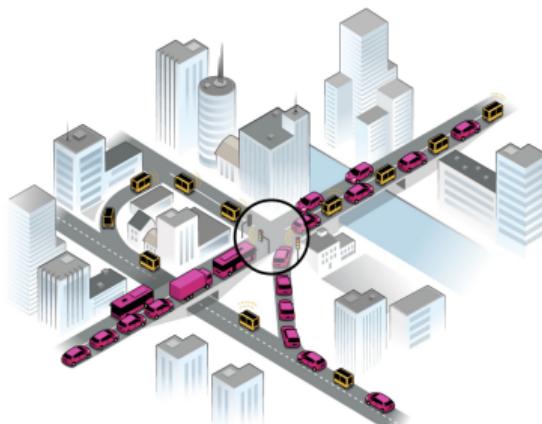
## Summary

Unprecedented progress in AV capabilities,  
operations, safety, and reliability.  
You can **be driven**.



European Research Council  
Financed by the European Union

## Research Gap



CAV

decision maker

## Autonomy

The focus was on making them capable to drive but the real challenge is beyond that

## Decisions

Now CAVs are 3yo kids and we taught them how to walk and not get lost.

The real problems come when they are teenagers and start making decisions.



# The Research Gap

## Gap

What will be the impact of **collective decisions** of Autonomous Vehicles on:

- 1 individuals
- 2 transport systems
- 3 cities
- 4 external (environment, equity, accessibility).



machine-dominated  
dystopia

or



synergy of human-machine  
**COEXISTENCE**



# Advantages

what CAVs can do better than humans?

Autonomous Vehicles (unlike humans):

- are designed to behave **optimally**,  
use all the data and compute power to make optimal decisions
- can **collaborate**,  
share information and cooperatively reach synergy
- may understand human behaviour:  
predict it and **anticipate** our decisions
- are automated and thus controllable  
by whom? owners → Big-Tech



synopsys™

LEVELS OF DRIVING AUTOMATION



erc  
European Research Council  
Enriching society through frontier research

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# Advantages

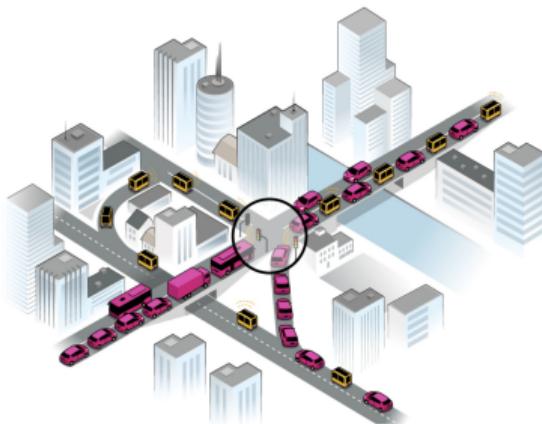
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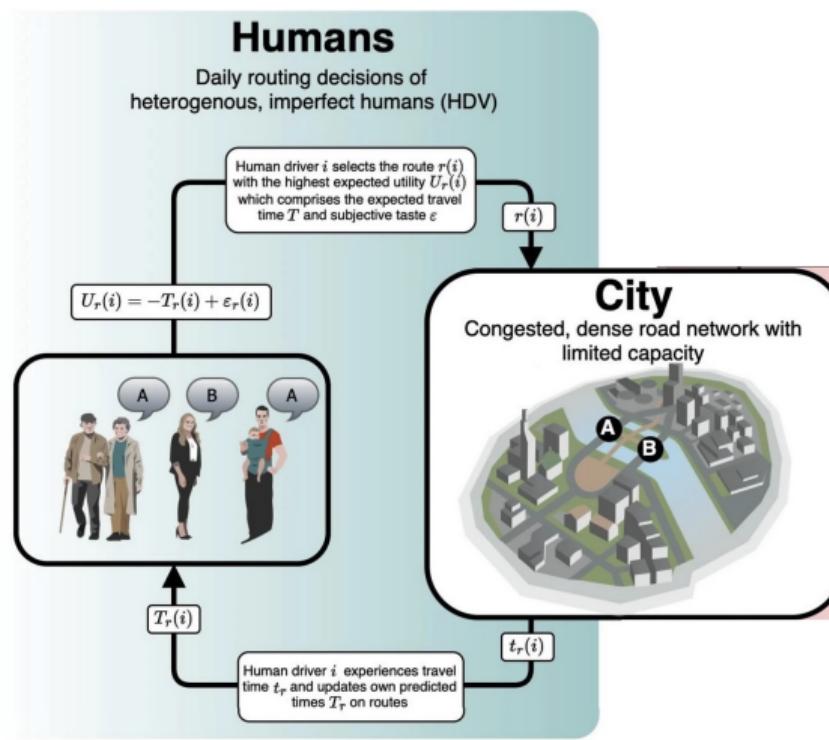


## Urban Routing Game



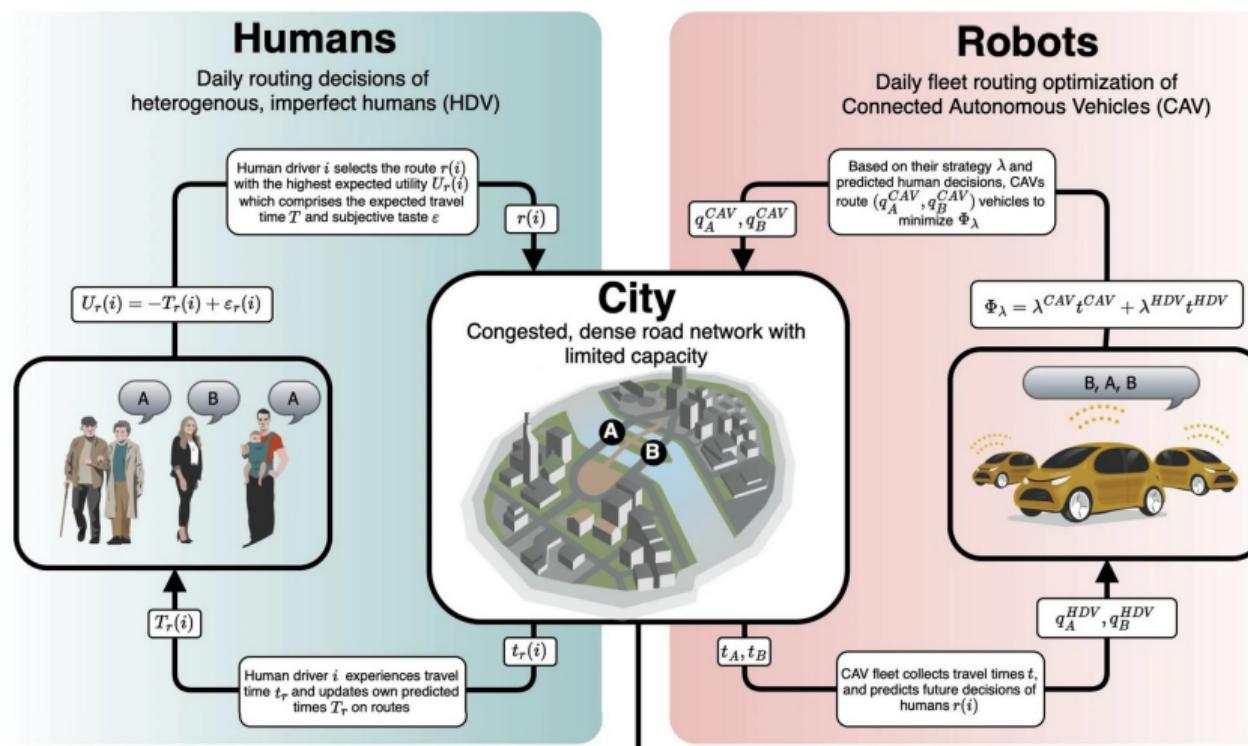
## The Urban Routing Game

Day-to-day repeated route-choice problem aka morning rush hour

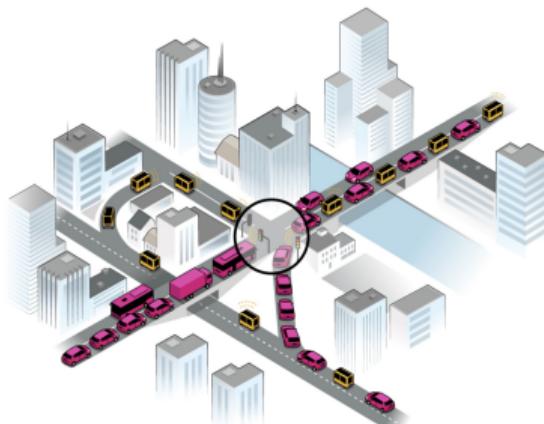


# The Urban Routing Game

Day-to-day repeated route-choice problem aka morning rush hour



## Findings



## General alarming

Studying the simplest two-route bottleneck macroscopic network, we discover<sup>1</sup> that CAV choices:



- are different
  - have impact on system performance
  - affect humans

<sup>1</sup>Jamróz, G., Akman, A. O., Psarou, A., Varga, Z. G. & Kucharski, B. Social implications of coexistence of CAVs and human drivers in the context of route choice. *Scientific Reports* **15**, 6768 (2025).

## Team credits



**Big** thanks to the team:

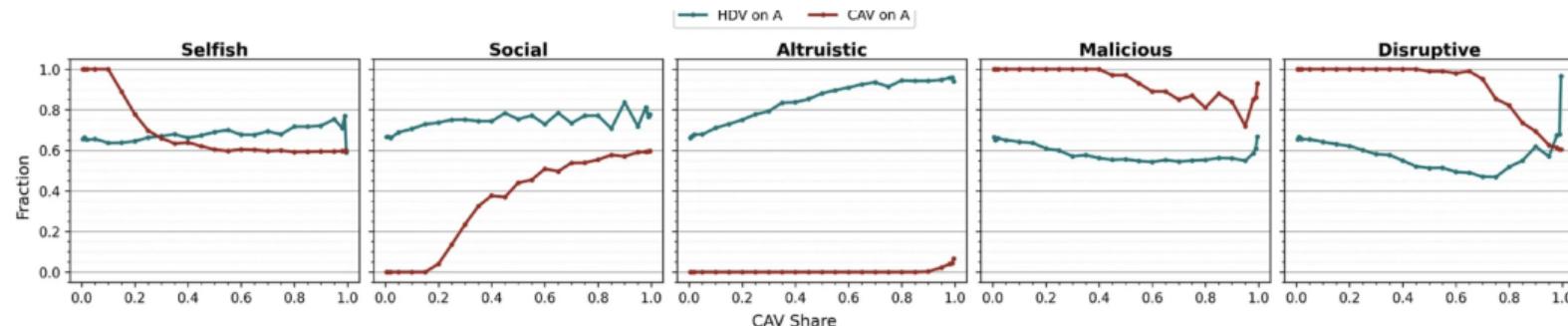
- Onur Akman
  - Anastasia Psarou
  - Grzegorz Jamroz
  - Michał Hoffman
  - Zoltan Varga
  - Paweł Gora
  - Łukasz Gorczyca
  - Michał Bujak
  - Sylwia Polak
  - ...



# Different choices

Studying the simplest of the two-route bottleneck macroscopic network, we discover<sup>2</sup> that:

CAV route choices (**blue-ish**) **differ significantly** from the choices of the remaining human driven vehicles (**brown-ish**).



optimal CAV choices depend on the market share (x-axis) and the **strategy** (panels).

<sup>2</sup>Jamróz, G., Akman, A. O., Psarou, A., Varga, Z. G. & Kucharski, R. Social implications of coexistence of CAVs and human drivers in the context of route choice. *Scientific Reports* 15, 6768 (2025).

# Fleet strategy controls the overall system performance

alarming<sup>3</sup>

## Strategy

- Humans:

$$U_i \approx \gamma^i t_i + \varepsilon$$

- Machines:

$$U_i = \gamma^i t_i + \gamma^{\text{CAV}} T_F + \gamma^{\text{HDV}} T_{\text{HDV}}$$

- $\gamma^{\text{CAV}}$  - how do you care for your group (fleet)?
- $\gamma^{\text{HDV}}$  - how do you care for others (humans)?

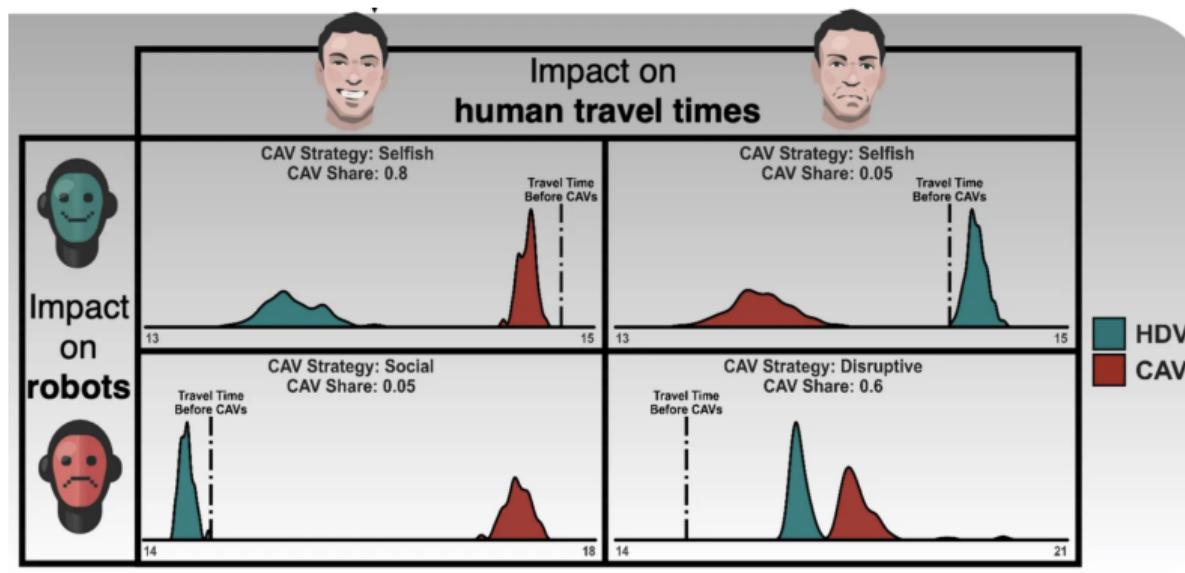


<sup>3</sup>Akman, A. O., Psarou, A., Varga, Z. G., Jamróz, G. & Kucharski, R. Impact of collective behaviors of autonomous vehicles on urban traffic dynamics: A multi-agent reinforcement learning approach. *arXiv preprint arXiv:2509.22216* (2025).

# Fleet strategy controls the overall system performance

alarming

In different scenarios the average travel time of both HDVs and CAVs may increase or decrease<sup>4</sup>.



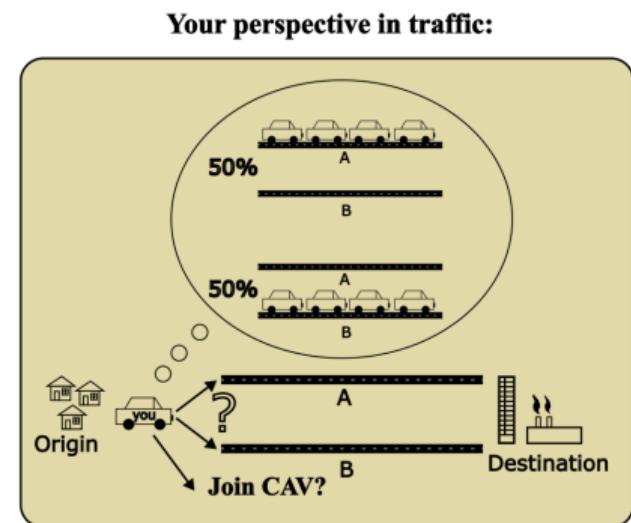
<sup>4</sup> Jamróz, G., Akman, A. O., Psarou, A., Varga, Z. G. & Kucharski, R. Social implications of coexistence of CAVs and human drivers in the context of route choice. *Scientific Reports* 15, 6768 (2025).

# Disequilibrating is a good strategy to maximise fleet market share

alarming

What to expect from a capitalist, big-tech players?<sup>5</sup>

- A fleet operator seeking market share may benefit from **controlled chaos**.
- **Travel-time oscillations** predictable for fleet, but not for humans.
- Frustration can push drivers to **switch to the fleet**.



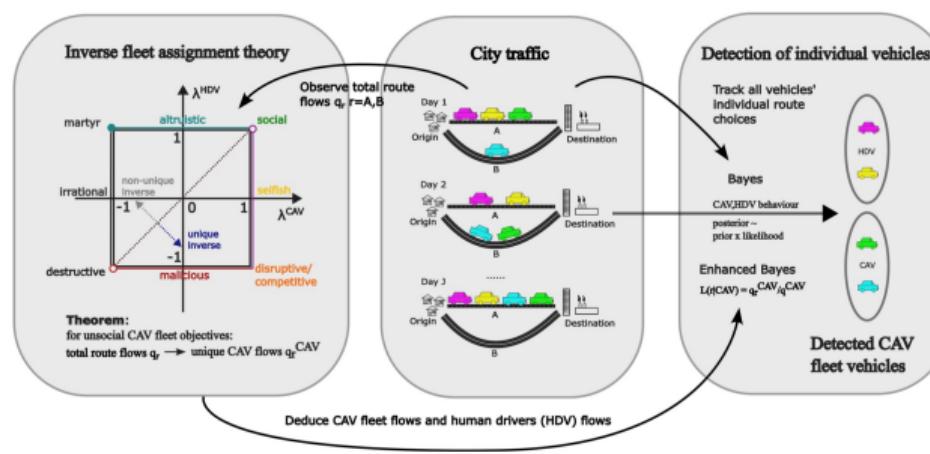
<sup>5</sup> Jamróz, G., Kucharski, R. & Watling, D. Market share maximizing strategies of CAV fleet operators may cause chaos in our cities. [arXiv preprint arXiv:2512.03524 \(2025\)](https://arxiv.org/abs/2512.03524).

# Unsocial fleet behaviours can be detected.

promising

- Can we **infer CAV flows** from total flows?
- Can we **detect** individual antisocial CAVs ?

**Finding:** detection/identification is feasible for **antisocial fleet objectives<sup>6</sup>**.



<sup>6</sup> Jamróz, G. & Kucharski, R. Detection of coordinated fleet vehicles in route choice urban games. Part I. Inverse fleet assignment theory. *arXiv preprint arXiv:2506.22966* (2025).

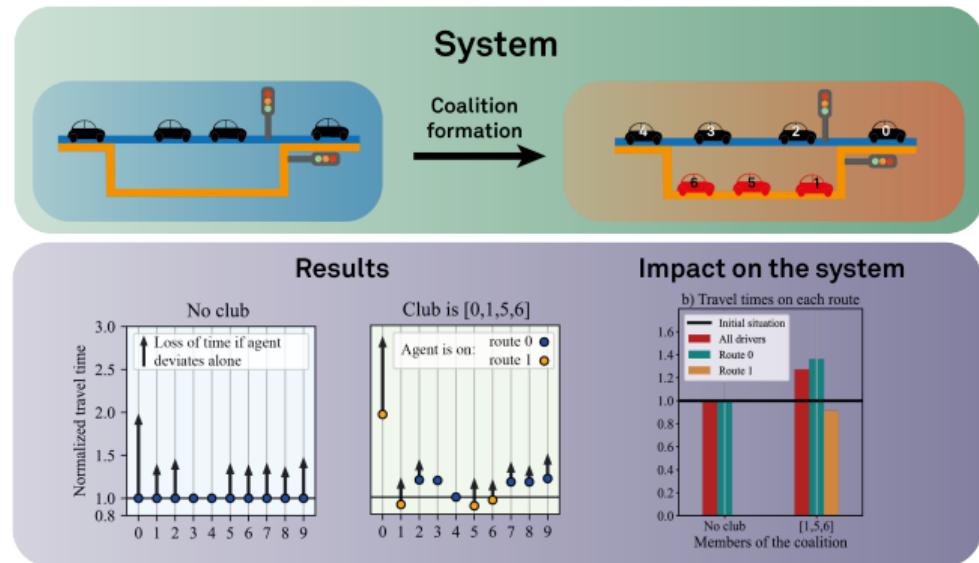
# CAVs may form exclusive clubs

alarming<sup>7</sup>

- CAVs can break away from Nash equilibrium by coordinating as a coalition.
- Coalitions reduce their travel times.
- At the expense of others (travelling longer).
- Coalitions are efficient only up to a size → exclusive clubs.

CAV elite?

Premium users of public space?



<sup>7</sup> Kucharski, R., Psarou, A. & Descormier, N. Equilibria in routing games with connected autonomous vehicles will not be strong, as exclusive clubs may form. *arXiv preprint arXiv:2510.12862* (2025).

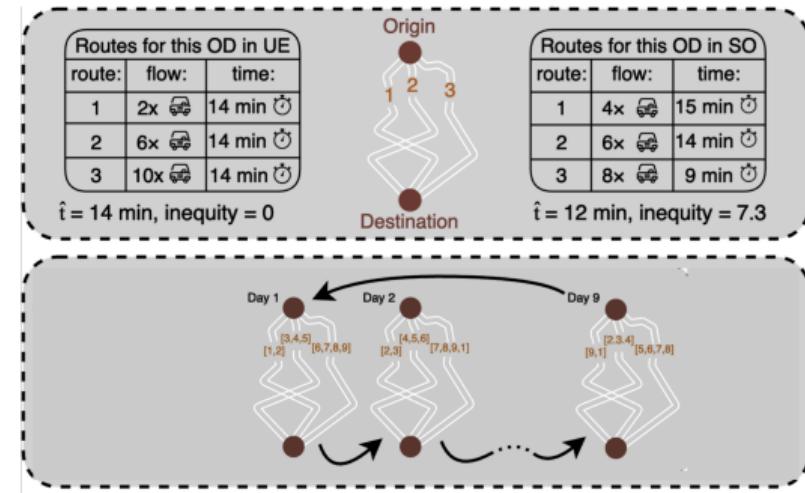
# Traffic can be both optimal and fair with CAVs

promising<sup>8</sup>

**Idea:** System-optimal routing for CAVs is efficient but unfair; we propose Wardropian Cycles to balance both.

**Concept:** Drivers follow optimal routes daily, but assignments rotate over multiple days to equalise average travel times.

**Takeaway:** In Barcelona 670 vehicle-hours of Price-of-Anarchy are eliminated daily



<sup>8</sup> Hoffmann, M., Bujak, M., Jamróz, G. & Kucharski, R. Wardropian Cycles make traffic assignment both optimal and fair by eliminating price-of-anarchy with Cyclical User Equilibrium for compliant connected autonomous vehicles. *arXiv preprint arXiv:2507.19675* (2025).

# State-of-the-art ML algorithms fail even on trivial routing tasks.

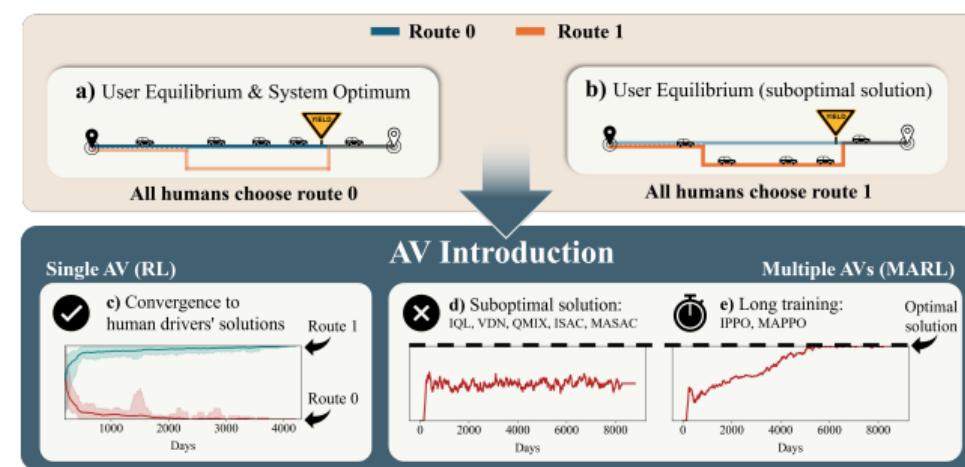
alarming

Reinforcement Learning (which already won in GO, Starcraft and breakthrough in AlfaFold) seems to be best suited for optimal fleet assignment task.

but<sup>9</sup>

## Reinforcement Learning

Even in a **trivial setting** (e.g., two routes, small fleet), state-of-the-art RL methods struggle to find optimal routing.



<sup>9</sup> Psarou, A., Kucharski, R. et al. Autonomous vehicles need social awareness to find optima in multi-agent reinforcement learning routing games. *AAMAS 2026, short paper* (2026).



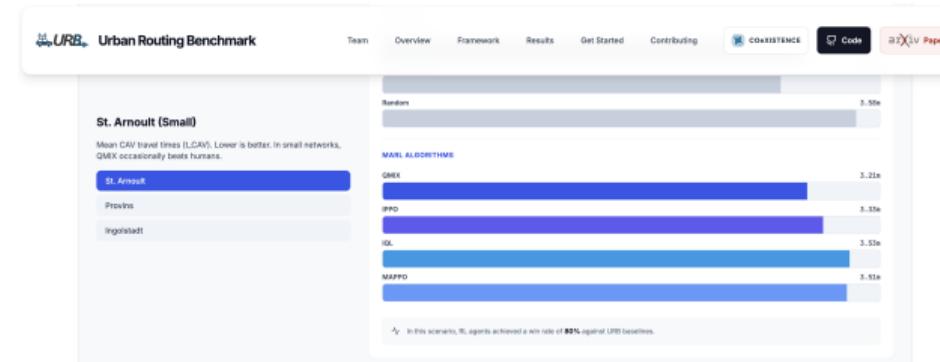
# Monitoring and catalyzing solutions

ML benchmark and leaderboard<sup>11</sup>

- URB (Urban Routing Benchmark)<sup>10</sup> for fleet routing with MARL.
- multiple real-world networks + demands, predefined tasks, baselines, metrics.

**Goal:** standardize evaluation and build a **leaderboard** for progress.

**Future:** Monitor and verify algorithms used by fleets.



<sup>10</sup> Akman, A. O., Psarou, A., Hoffmann, M., Gorczyca, Ł., Kowalski, Ł., Gora, P., Jamróz, G. & Kucharski, R. URB - Urban Routing Benchmark for RL-equipped Connected Autonomous Vehicles. NeurIPS 2025. eprint: <https://doi.org/10.48550/arXiv.2505.17734> (2025).

<sup>11</sup> [www.urbenchmark.com](http://www.urbenchmark.com)

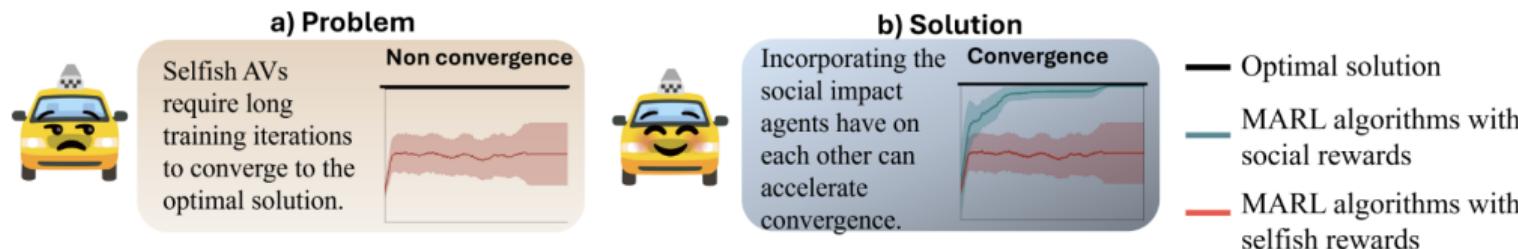


# It is better to be a good socially aware CAV than selfish promising

- Social awareness in rewards (e.g., marginal-cost) works<sup>12</sup>

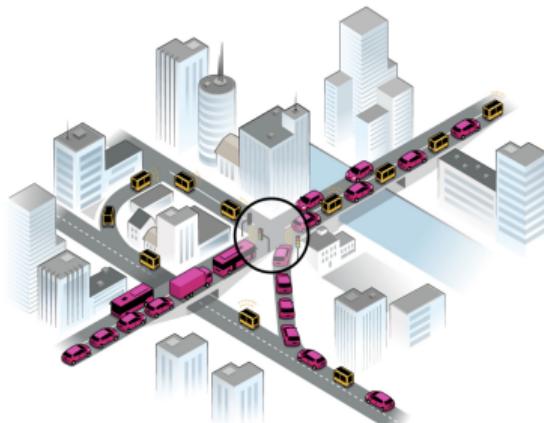
$$\frac{\partial T}{\partial a_i}$$

**Impact:** improve both system-wide performance and individual agents.



<sup>12</sup> Psarou, A., Kucharski, R. et al. Autonomous vehicles need social awareness to find optima in multi-agent reinforcement learning routing games. *AAMAS 2026, short paper* (2026).

## Conclusion



## Insights

## Things can always get worse

- Delegating strategic decisions to CAVs (effectively to big-tech) will have consequences.
  - It may change our cities.
  - Making them better or worse.
  - ... inclusive or exclusive.
  - Harsh battlefield with *winner takes it all* competition (remember Uber?)

Call for action

We need to report this, understand, simulate, demonstrate and get ready before it comes.

The policymakers shall look ahead and prepare our public spaces into what's coming.

Society needs to participate, before exploited (again)



# COEXISTENCE?

### Future of cities with autonomous vehicles.<sup>13</sup>

Thank you for your attention,  
welcome to discuss

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