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SAMoD: Shared Autonomous Mobility-on-Demand using Decentralized Reinforcement Learning

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1. Context and objectives: Mobility-on-Demand (MoD) with Shared Autonomous Vehicles (SAVs)

	Taxi	Car-Sharing	SAV
Pick-up	Anywhere covered	Stations or where available	Anywhere possible
Drop-off	Anywhere covered	Same station or where authorized	Anywhere possible
Parking	Station or private parking	Stations or on-street	Dynamic and adaptive
Rebalancing	Selfish or static	Operator- [1] or user-based [2]	Dynamic [3] and adaptive [4]

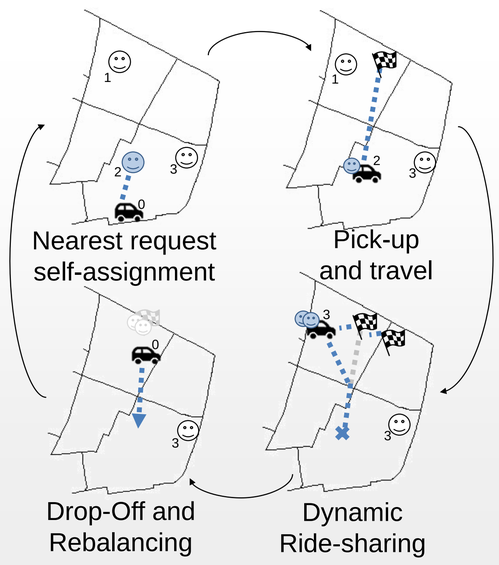
- Advantages of SAVs for MoD:
  - ✓ fully flexible fleet size
  - ✓ robots (almost) never need to take a break
  - ✓ can be summoned everywhere
  - ✓ can be very efficient if ride sharing enabled [5, 6]
- Challenges for SAVs:
  - dynamic adaptation to demand (and/or anticipation)
  - limit empty mileage [7]
  - optimize SAV-rider assignment (especially with ride sharing)

2. Related work versus decentralized and learning

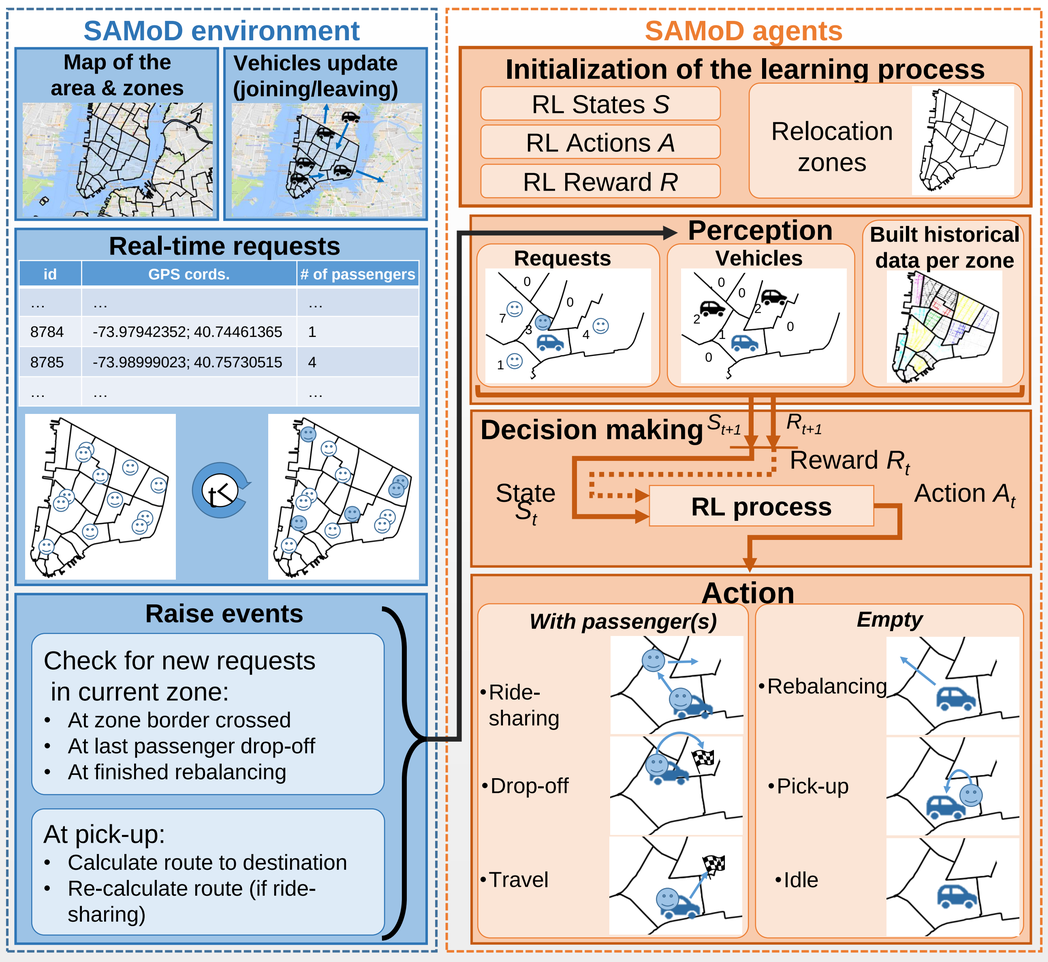
	Centralized	Decentralized	Learning
Several SAV companies	✘	✓	✓
Dynamic fleet size	✘	✓	✓
Optimized assignment	✓ limited scalability	✘	✘
Dynamic ride-sharing	✓ requires full knowledge [5]	✓	✓
Rebalancing	✓using historical data [3, 1]	✓ using a network partition [8, 9]	✓adaptive [10] and proactive
Used data	Full network knowledge [3, 5]	Local knowledge	Local knowledge

3. SAMoD agents

- Perception:
  - Requests and vehicles in current zone
  - Built historical data per zone
- Decision making:
  - Reinforcement learning (Q-learning)
  - Reward: to have passengers
- Actions:
  - Pick-up (including ride sharing)
  - Rebalance to zone
  - Do nothing



4. SAMoD system architecture



5. Simulation set-up

- Requests (NYC taxi data):
  - 50 consecutive Tuesdays
  - One request:
    - time the user requested the trip;
    - number of passengers
    - pick-up location
    - drop-off location
    - pick-up zone (id)
    - drop-off zone (id)
- Evaluation:
  - System:
    - served requests
    - timed-out requests (10 min)
  - Riders:
    - waiting time t_w
    - detour time t_d
    - travel time TT
  - Vehicles:
    - vehicle miles travelled VMT: average, empty, engaged, shared.
    - occupancy
- Scenarios:

	Summary	Assignment	Rebalancing	Ride sharing
Baselines	C	Centralized	No	No
	D	Decentralized	No	No
	C_RB	Centralized	Yes	No
	D_RB	Decentralized	Yes	No
	C_RS	Centralized	No	Yes
	D_RS	Decentralized	No	Yes
	C_RB_RS	Centralized	Yes	Yes
	D_RB_RS	Decentralized	Yes	Yes
SAMoD	S_RB	Learnt	Learnt	No
	S_RB_RS	Learnt	Learnt	Learnt current zone only
	S_RB_RS+1	Learnt	Learnt	Learnt current zone+1
	S_RB2_RS+1	Learnt	Learnt (limited)	Learnt current zone+1

6. Results (7-10am peak hour period)

		No RB, No RS		Rebalancing		Ride-sharing		RB and RS		SAMoD			
		C	D	C_RB	D_RB	C_RS	D_RS	C_RB_RS	D_RB_RS	S_RB	S_RB_RS	S_RB_RS+1	S_RB2_RS+1
System	Satisfied requests	29667	35388	30191	36913	38327	38368	38346	38407	35691	37790	37679	36159
	% of total requests	76.4	91.13	77.75	95.06	98.7	98.81	98.75	98.91	91.91	97.32	97.03	93.12
	Not served requests	8675	3098	8150	1590	0	54	0	11	2903	693	726	2242
	% of total requests	22.34	7.98	20.99	4.09	0	0.14	0	0.03	7.48	1.78	1.87	5.77
Riders	Avg t_w (min)	11.63	5.48	11.07	4.57	2.41	2.56	2.1	2.6	2.87	2.46	2.27	2.49
	Avg TT (min)	5.8	5.69	5.79	5.72	10.31	9.21	10.19	8.73	5.69	9.11	12.03	12.12
	Avg t_d (min)	0	0	0	0	4.57	3.47	4.44	2.99	0	3.39	6.31	6.49
Vehicles	Avg VMT	863.8	735.79	884.71	861.4	690.28	716.49	760.06	845.02	882.85	865.94	869.94	644.32
	Avg empty VMT	428.48	228.29	442.24	330.04	117.02	147.9	181.56	268.52	371.95	352.6	335.81	147.37
	Avg engaged VMT	435.32	507.5	442.47	531.36	573.26	568.59	578.5	576.5	510.91	513.34	534.13	496.95
	Avg shared VMT	103	120.55	103.78	125.54	382.75	324.74	376.86	301.96	115.84	330.3	433.86	409.11
	Avg occupancy	1.47	1.48	1.47	1.48	2.67	2.39	2.63	2.27	1.45	2.52	3.13	3.19

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