Adaptive Electric Vehicle Charging Infrastructure Planning

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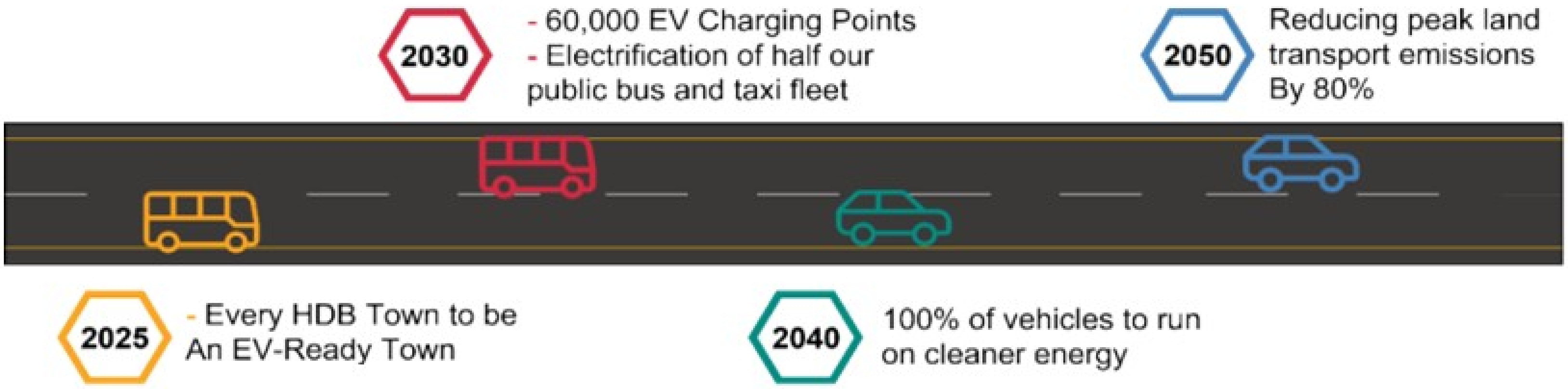
Charging Infrastructure Deployment Vision

- The number of fast chargers increased by 330,000 globally in 2022[1].



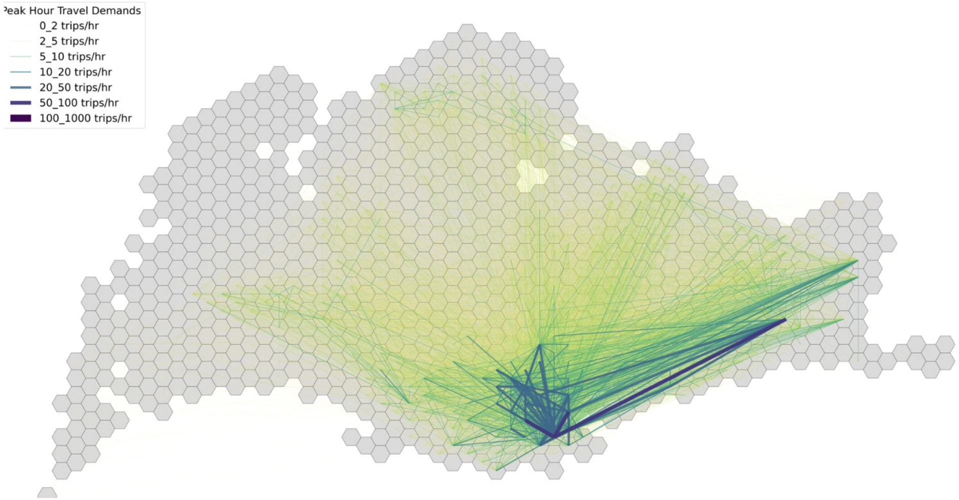
Overview of EV Road Map in Singapore

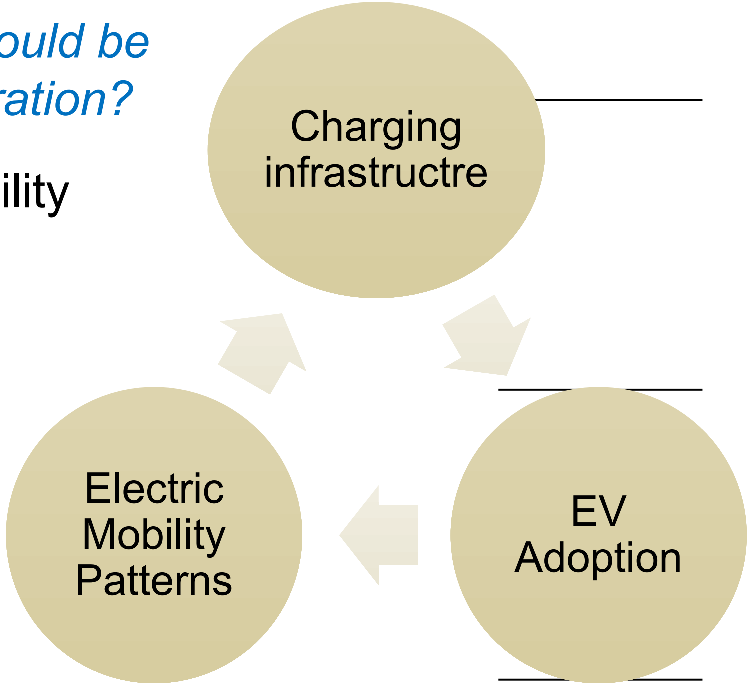
[1] Global EV Outlook 2023 Catching up with climate ambitions, IEA, 2023
[2] Our EV Vision, LTA, https://www.lta.gov.sg

Main Question??

When, ***where*** and ***what capacity/type*** *of chargers should be deployed in future* ***conditional*** *on the existing configuration?*

Other uncertain factors: Technology & Land use ⇔ Mobility



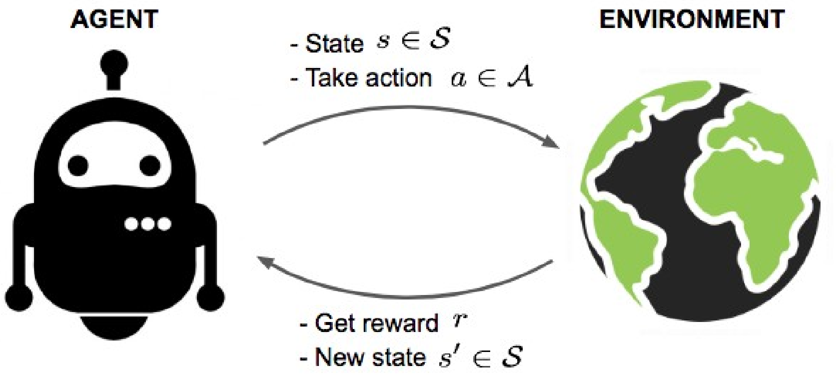


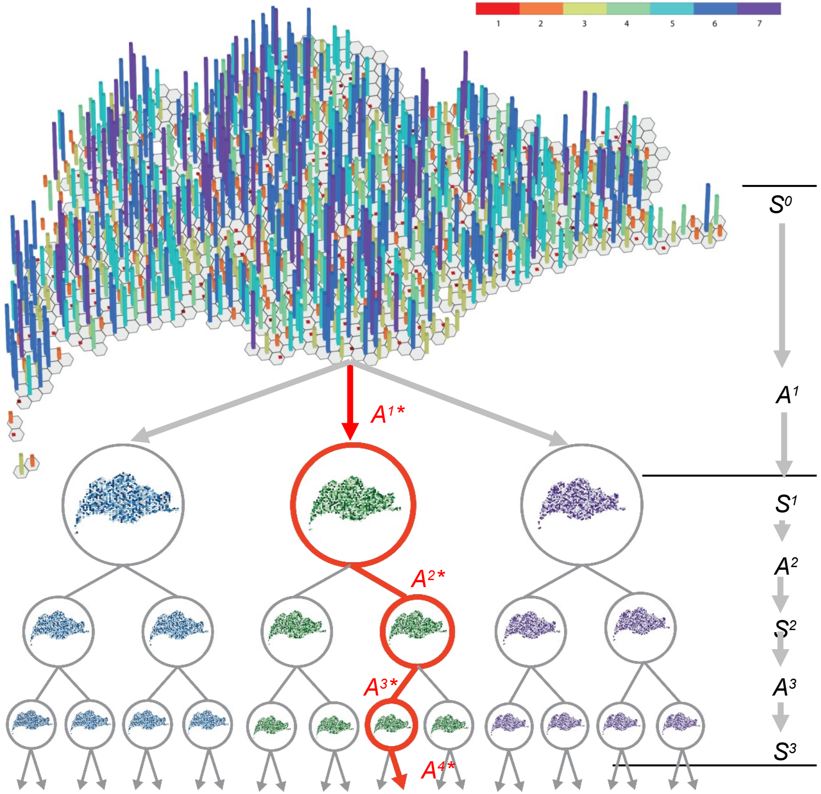
Design today's charging infrastructure considering evolving charging demand

Proposed Idea

Planning decision support (PDS) tool for a **multi-stage** charging infrastructure planning at an ***urban scale*** *considering*

- *EV adoption & mobility patterns*
- *Uncertainty*
- *Spatial constraints*





Sequential Decision-Making Approach

Three modules and ***two super agents*** optimally controlled at distinctive frequencies, which interact with the system in an ***AI gym environment***

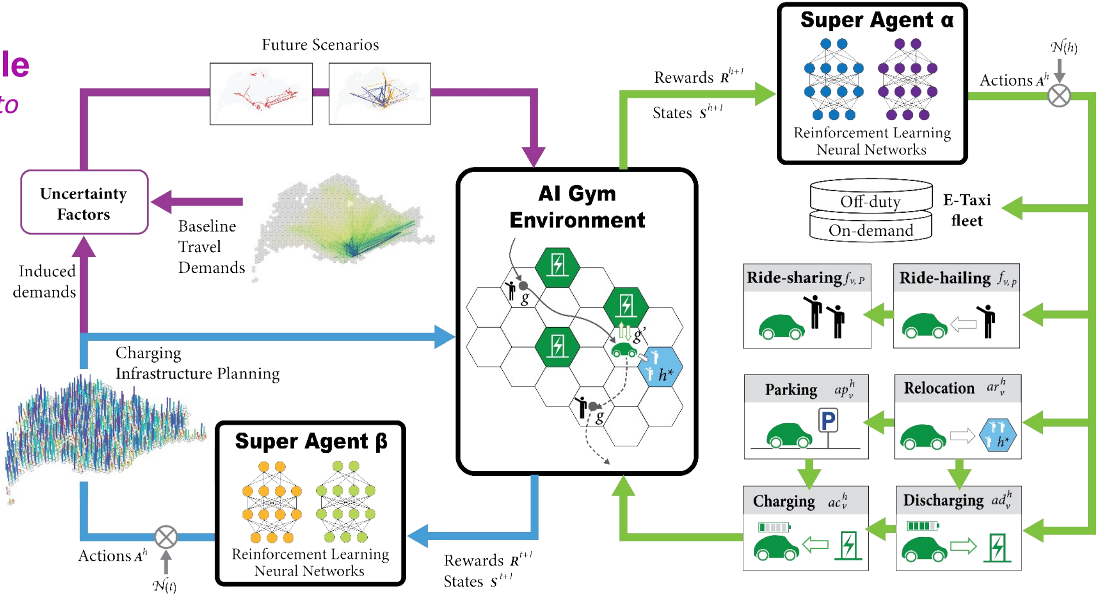
Trip Synthesis Module

mapping uncertainty factors to travel demands (include induced demands)

Decision-making Module

Evolving charging infrastructure deployment or dismantle policy

(decision frequency t = 1 month)



Agent-based Traffic Simulation Module

Model fine-grained multi-behaviours of traffic dynamics of E-taxi

(simulation frequency = sec, observation frequency h = min)

Objective Function and Reward

- The **objective function** is composed of ***four parts***

$$r_i^t = \eta \sum_{v\in \mathrm{V}} \sum_{h\in \mathrm{H}^t} \beta_{v,i}^h e^{h,t} - \eta \sum_{v\in \mathrm{V}} \sum_{h\in \mathrm{H}^t} \beta_{v,i}^h c^{h,t} - \sum_{q\in \mathrm{Q}} CO_q n_{i,q}^t - \sum_{q\in \mathrm{Q}} CS_q \alpha_{i,q}^t$$

Revenue from charging | Electricity cost | Maintenance cost (existing chargers) | Set-up cost (new chargers)

η *Time multiplier (=30)*

$\beta_{i,v}^h$ *Binary charging state of v at cell i at h*

$e^{h,t}$ *Charging fare at time h of t planning step*

$c^{h,t}$ *Electricity price at time h of t-period*

$n_{i,q}^t$ *Number of installed chargers*

$\alpha_{i,q}^t$ *(decision variable) number of chargers type q to be deployed*

- The **reward** estimates the expectation over all ***discounted accumulative reward*** of future steps (from t' to the end)

$$\max_{\alpha_{i,q}^t} \mathop{\mathbb{E}}_{i\sim \mathrm{I}} \left(\sum_{t=t'}^{\mathrm{T}} \gamma^{t-t'} r_i^t \right)$$

γ *discount factor*

Uncertainties

- **Battery technology and variations in charging conditions**

Battery size, charging power and charging efficiency affects charging time

$$ct_{v,i,q}^{h,t} = \frac{b_v^t(USOC_v - soc_v^{h,t})}{pow_{i,q} \cdot \mathbf{f}(pow_{i,q})}$$

- **Induced trip based on EV and E-taxi**

New infrastructure layout affect trips and charging patterns

$$d_{i,i'}^{t+1} = \mathbf{G}(d_{i,i'}^t; \alpha_{i,q}^t)$$

$ct_{v,i,q}^{h,t}$	*charging time*
$USOC_v$	*upper limit of the state of charge*
$\mathbf{f}(\cdot)$	*charging efficiency function*
b_v^t	*Battery size of E-taxi at t*
$soc_v^{h,t}$	*state of charge of v at h*
$d_{i,i'}^t$	*E-taxi demand between i, i'*
$\mathbf{G}(\cdot)$	*E-taxi demand forecasting function*

Action (Decision Variable)

Number of type q-chargers to be deployed at a location (cell) i in planning period t

$$\alpha_{i,q}^{t} \in \mathbb{N}_{[-n_{i,q}^{t}, N_{i,q} - n_{i,q}^{t}]} \qquad \forall h \in \mathrm{H}^{t}, t \in \mathrm{T}, q \in \mathrm{Q}$$

States

Charging demand satisfaction rate: $ss_i^t = \sum_{h \in \mathrm{H}^t} \sum_{v \in \mathrm{V}} \frac{cha_{i,v}^{h,t}}{req_{i,v}^{h,t}}$

Deployment progress rate: $sd_i^t = \sum_{q \in \mathrm{Q}} \frac{n_{i,q}^t}{N_{i,q}^t}$ $\quad t \in \mathrm{T}$

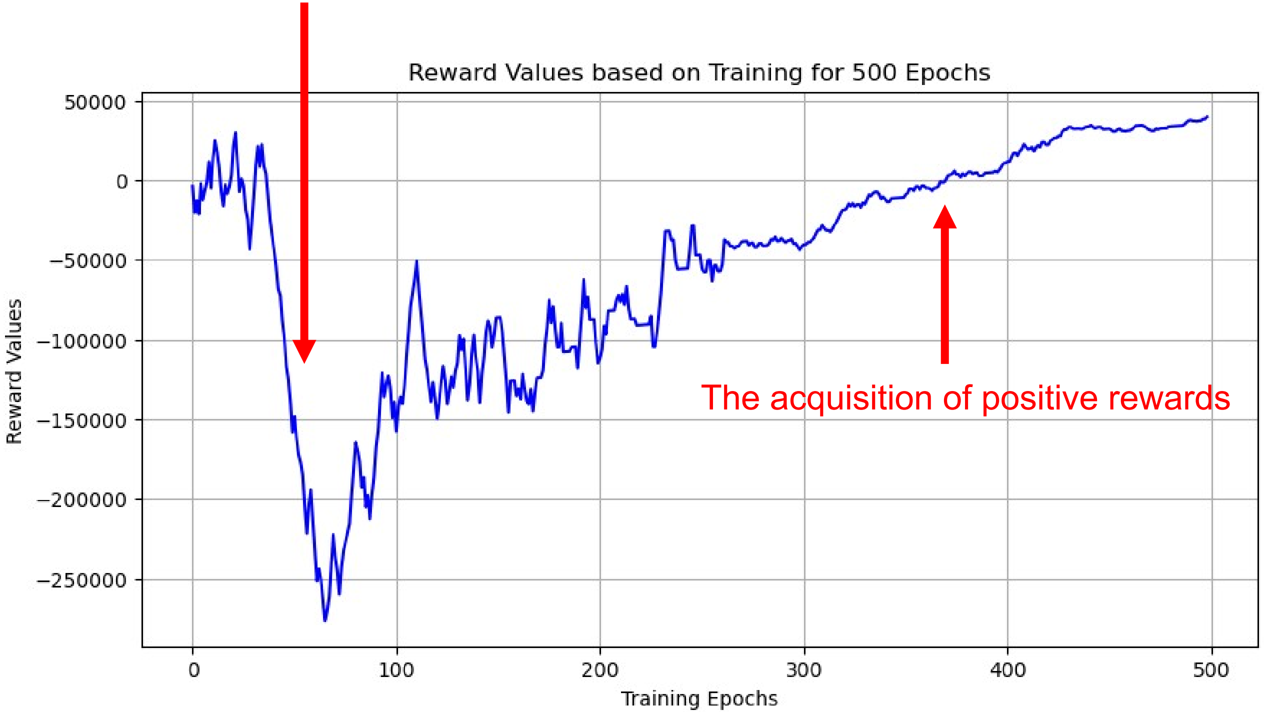
Average occupancy rate of chargers: $so_i^t = \mathop{\mathbb{E}}_{h \in \mathrm{H}^t} \left(\frac{nop_{i,q}^h}{n_{i,q}^t} \right)$

Average waiting time ratio: $sw_i^t = \mathop{\mathbb{E}}_{v \in \mathrm{V}} \left(\frac{tim_{i,v}' - tim_{i,v}}{|\mathrm{H}^t|} \right)$

Results

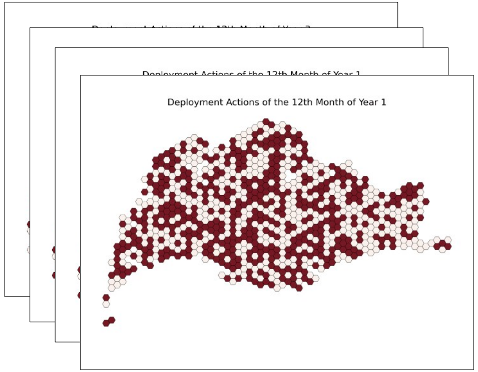
Exploration phase for all possible layout
(with large noise in action values)

r_i^t

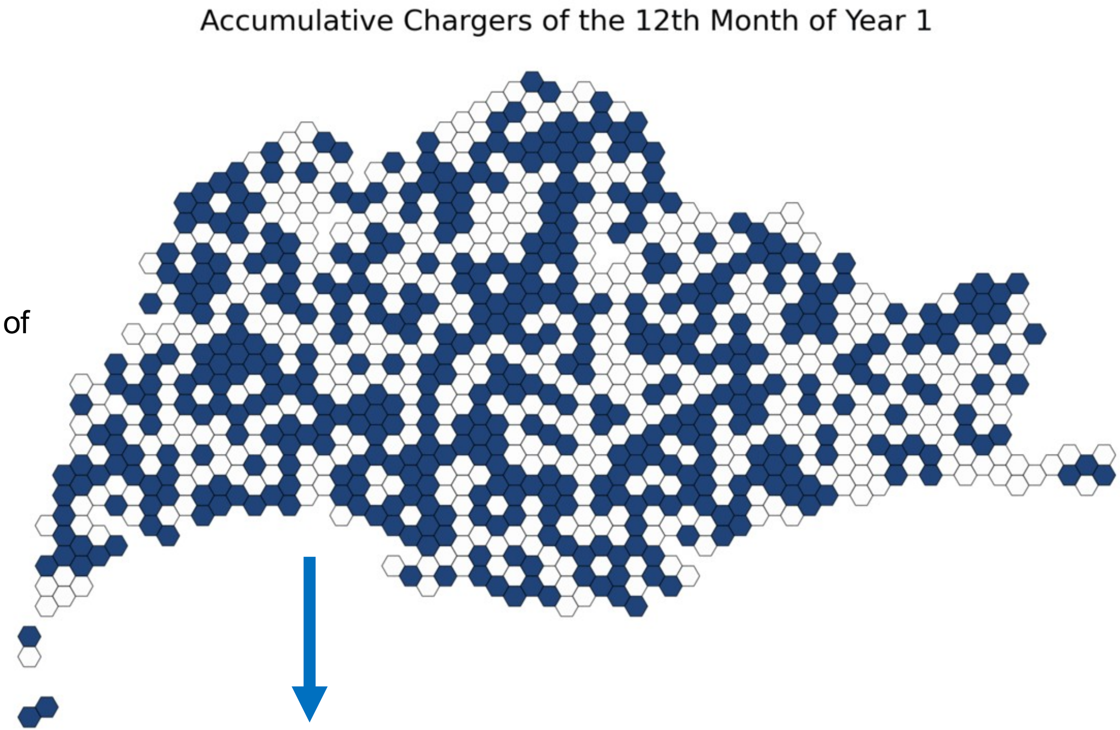


The acquisition of positive rewards

Results



Cumulates of changes in chargers



Evaluation of r_i^t

$$\alpha_{i,q}^{t} \in \mathbb{N}_{[-n_{i,q}^{t}, N_{i,q}-n_{i,q}^{t}]}$$

RL model takes an action at each month

Thank You!

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