PMAPS 2022

Data Driven EV Planning and Sharing

Prof Z.Y. Dong

Nanyang Technological University

14 June 2022

Outline

- Introduction
- EV Trials
- Data Driven Framework
- Game Model for Budget
- Computational Methods
- EV Sharing Model
- Conclusions

Introduction

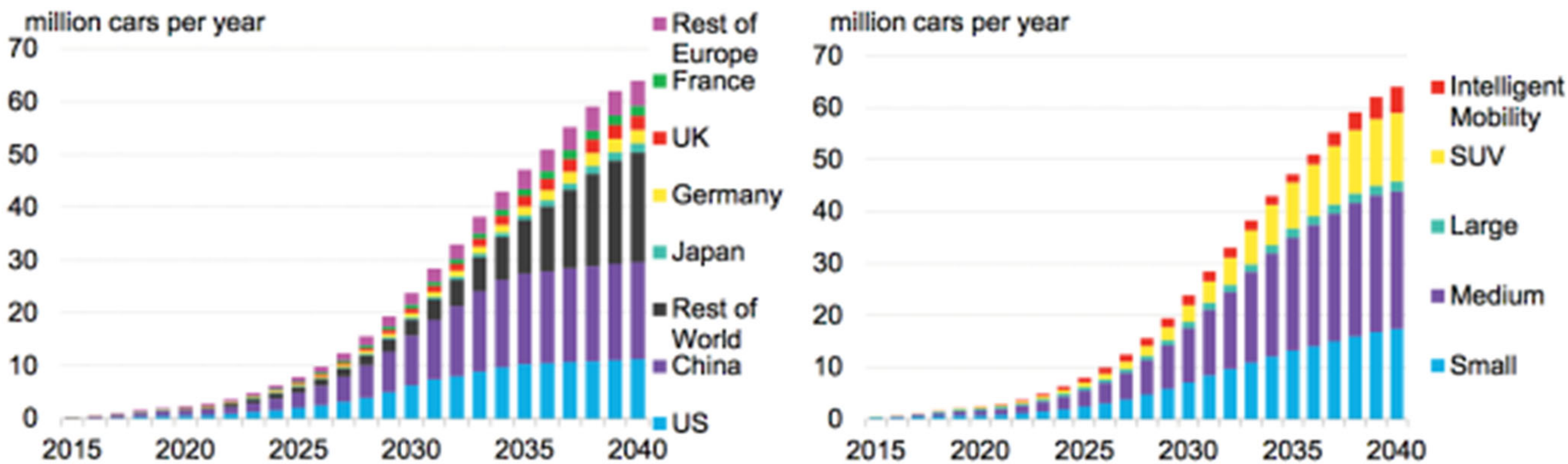


Figure 1. The global EV market and its projection [new-energy-outlook]

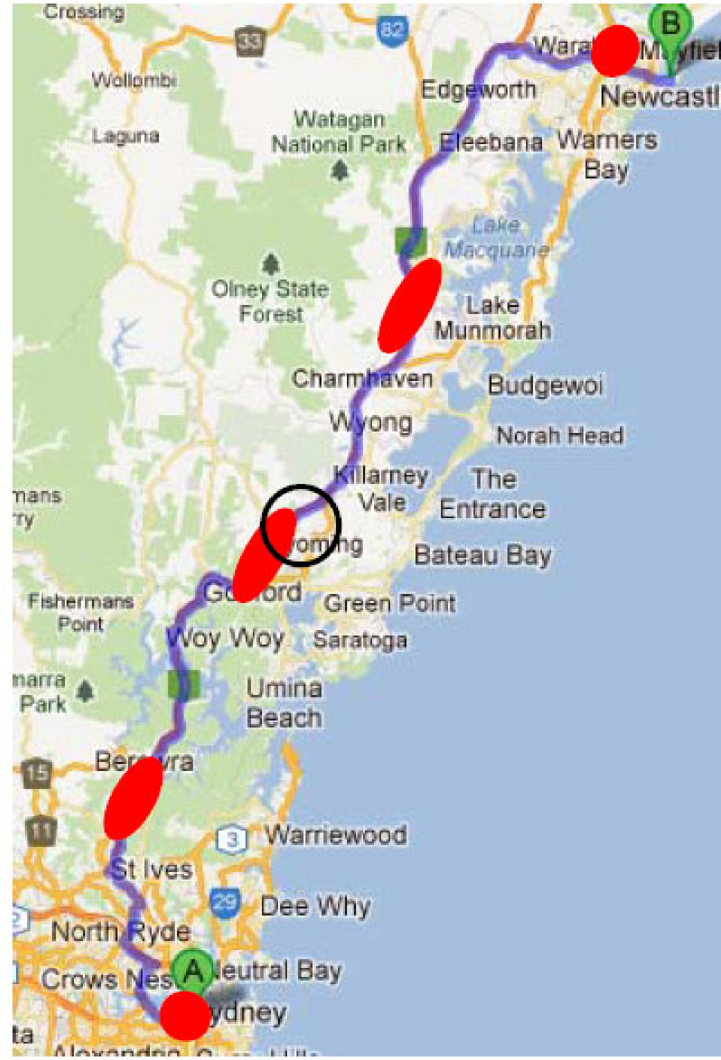
- Increasing number of **Electric Vehicles (EVs)** in global market.
- Due to **electrification** of the transportation sector, EV sales are on the rise.
- Many **EV charging infrastructures** are required in near future.

Source: https://about.bnef.com/new-energy-outlook/

SGSC EV Trial

- *The overall objective of the Electric Vehicle Project was to understand the potential impact of wide scale uptake of electric vehicles on the electricity distribution network.*
- **Road trials**
  - EVs to home trial users and fleet users for a period of 24 months.
  - The aim of the road trials was to provide data on the advantages and limitations of various charging regimes.
- **Charging infrastructure**
  - The charging infrastructure involved deployment of a charging network of 46 standard charge and six fast charge stations
- **Uptake and behaviour model**
  - To provide data to assist networks in understanding the impact of EV charging at lower levels of the network.
- **Grid impact modelling**
  - This enabled an understanding of when and where a network was over-stressed or where supply was likely to go out of specification.

Source: Smart Grid, Smart City info clearing house



Map Between Sydney & Newcastle
(showing typical search ring areas)

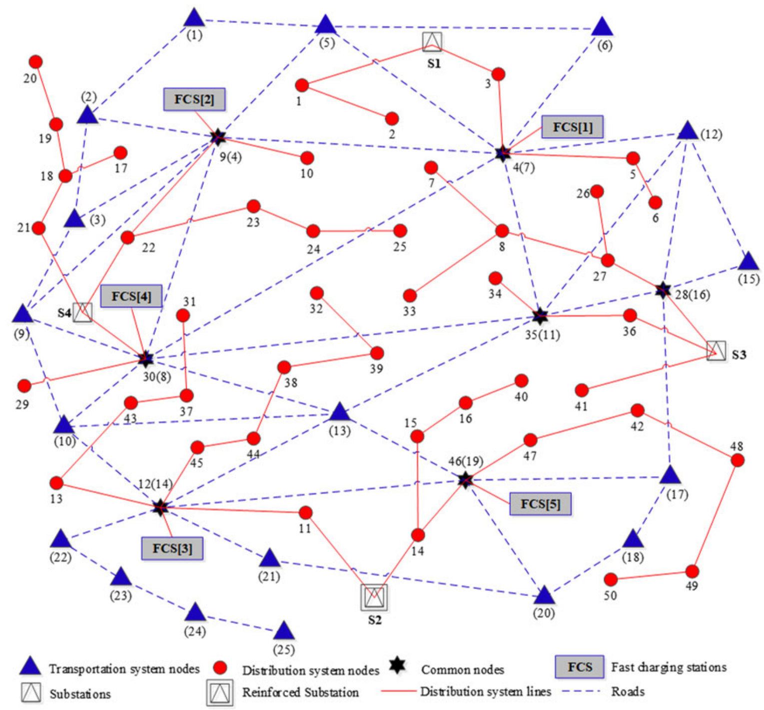
Charging Infrastructure Planning

- Issues:

1. Deficient charging infrastructure
2. Utilise existing asset bases (electricity infrastructure, parking).
3. Look at opportunities to partner with the private sector.
4. Develop innovative solutions to future infrastructure needs

- Planning criteria:

1. Geographic distances/trip planning, addressing “range anxiety”
2. Electrical network infrastructure
3. Road access, electrical, vehicle and disembarkation strategy
4. Future changes of surrounding land use



Data Driven EV Charging Planning

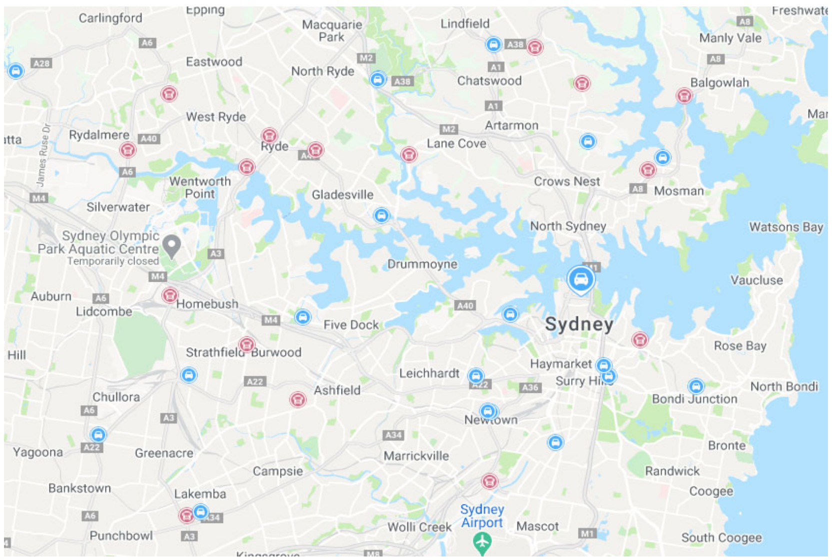


Figure 3. The public traffic flow recorded by road sensors

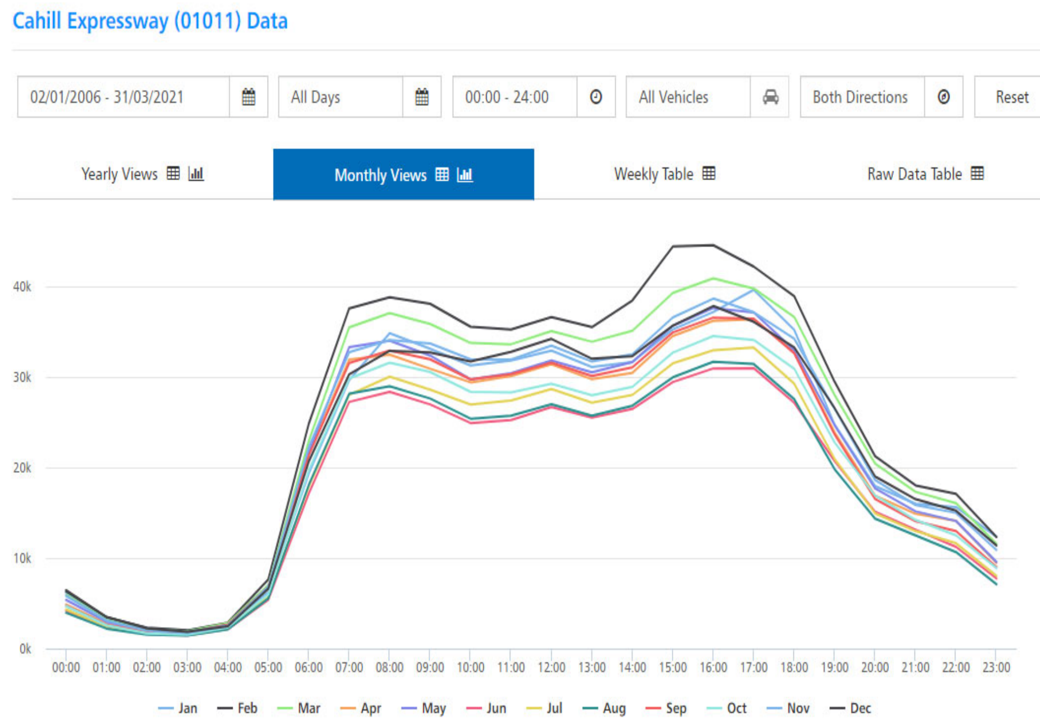


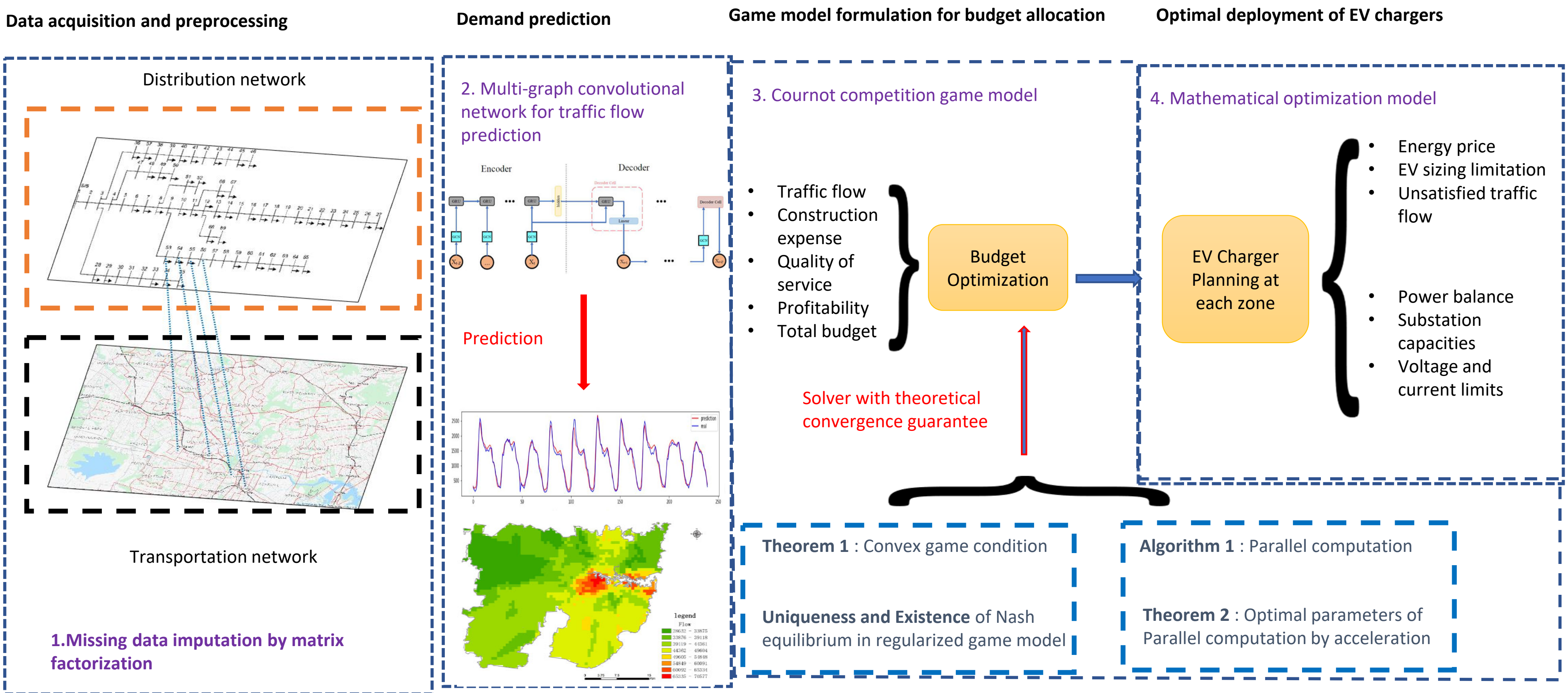
Figure 4. The monthly public traffic flow on Cahill expressway with respect to 24 hours

- Data privacy concern for individual GPS tracking
- Only public traffic flow data available [RMS-NSW]
- **Origin-destination (OD) pairs** for EV charging demand
- **Spatial-temporal** dependency of traffic flow

Source: https://www.rms.nsw.gov.au/about/corporate-publications/statistics/traffic-volumes/aadt-map/index.html#/?z=10

[3]https://www.rms.nsw.gov.au/about/corporate-publications/statistics/traffic-volumes/aadt-map/index.html#/?z=10

Scalable Efficient Big Data Pipeline



Architecture : Predict-then-optimise

Optimal Sizing of EV Chargers

Objective-maximize revenue

$$\max_{\{\zeta_{i,k}^m, n_{i,k}^m\}} \left\{ \sum_{m\in M} \sum_{i\in I} \sum_{k=1}^{3} \left(\Delta T \eta_i (r_k - c_e) p_k n_{i,k}^m - c_{1,i,k}\zeta_{i,k}^m - c_{2,i,k} n_{i,k}^m \right) - \sum_{q\in Q} c_p \lambda_{OD}^q T_q \right\}$$

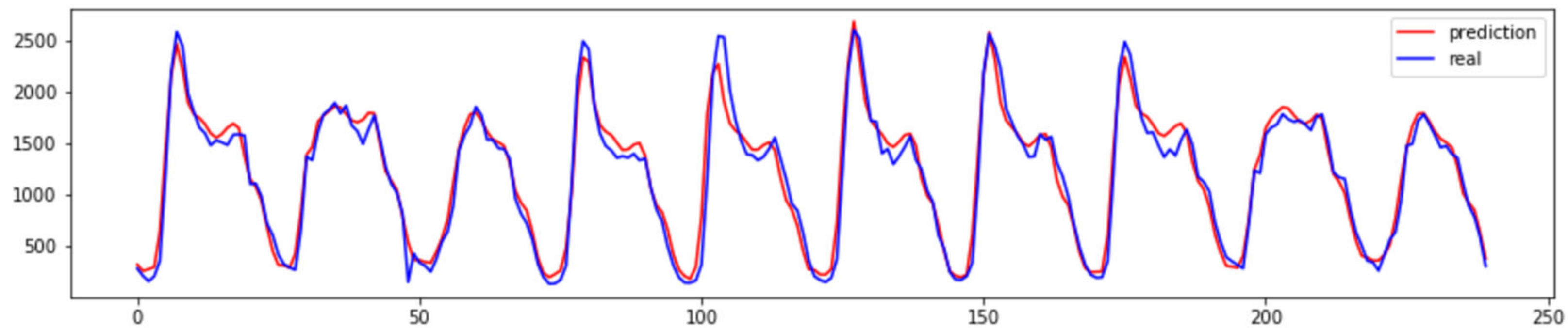
s.t. $$\sum_{\{j|(i,j)\in \hat{A}_q\}} \lambda_{ij}^q - \sum_{\{j|(i,j)\in \hat{A}_q\}} \lambda_{ji}^q = \begin{cases} 1, & i = O \\ -1, & i = D \\ 0, & i \neq O, D \end{cases}$$ Traffic balance

$$\sum_{q\in Q} \sum_{\{j|(j,i)\in A_q\}} T_q \lambda_{ji}^q \leq \sum_{m\in M} \sum_{k=1}^{3} \Psi(n_{i,k}^m), \forall i \in I$$ Serviceability

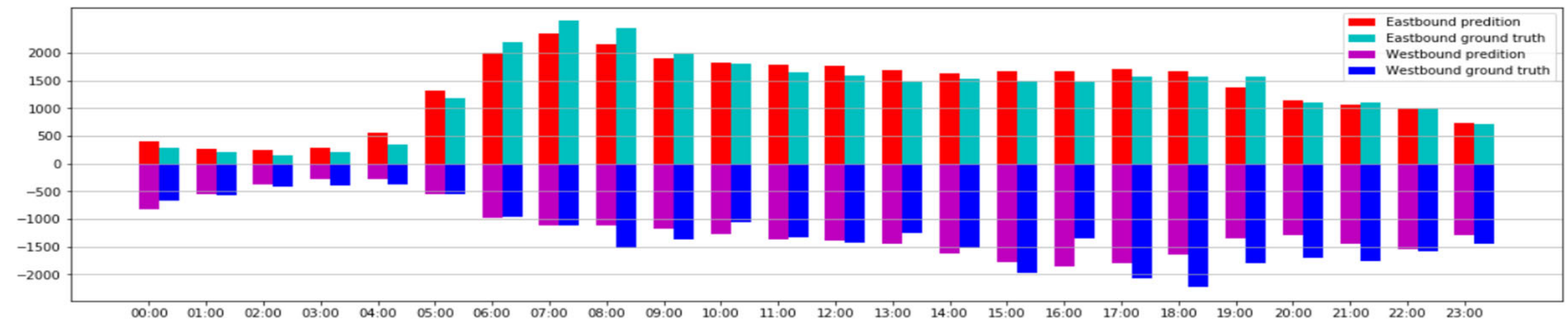
$$\sum_{k=1}^{3} \left(c_{1,i,k}\zeta_{i,k}^m + c_{2,i,k} n_{i,k}^m \right) \leq \hat{x}_{m,i}$$ Budget

Where $n_{i,k}^m$ is the number of level k charger at zone i built by service provider m. $\zeta_{i,k}^m$ indicates if there is a level k station built at node i. λ_{ij}^q is the fraction of traffic flow from i to j on path q.

Experiment: EV charging demand estimation (2)



(a). 10-day prediction of one direction traffic flow



(b). 1-day prediction of bi-direction traffic flow

Figure 7. The visualization of prediction results

Experiment: EV charging demand estimation (2)

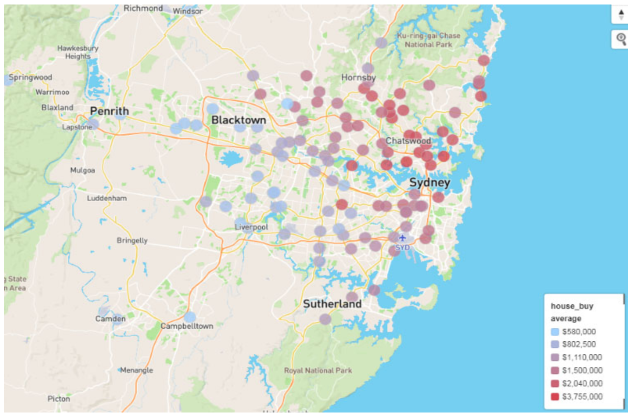


Figure 8. The visualization of average house price

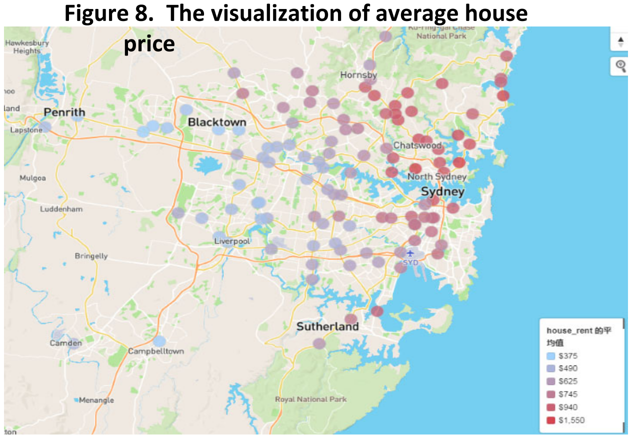


Figure 9. The visualization of average rent price (source from www.realestate.com.au)

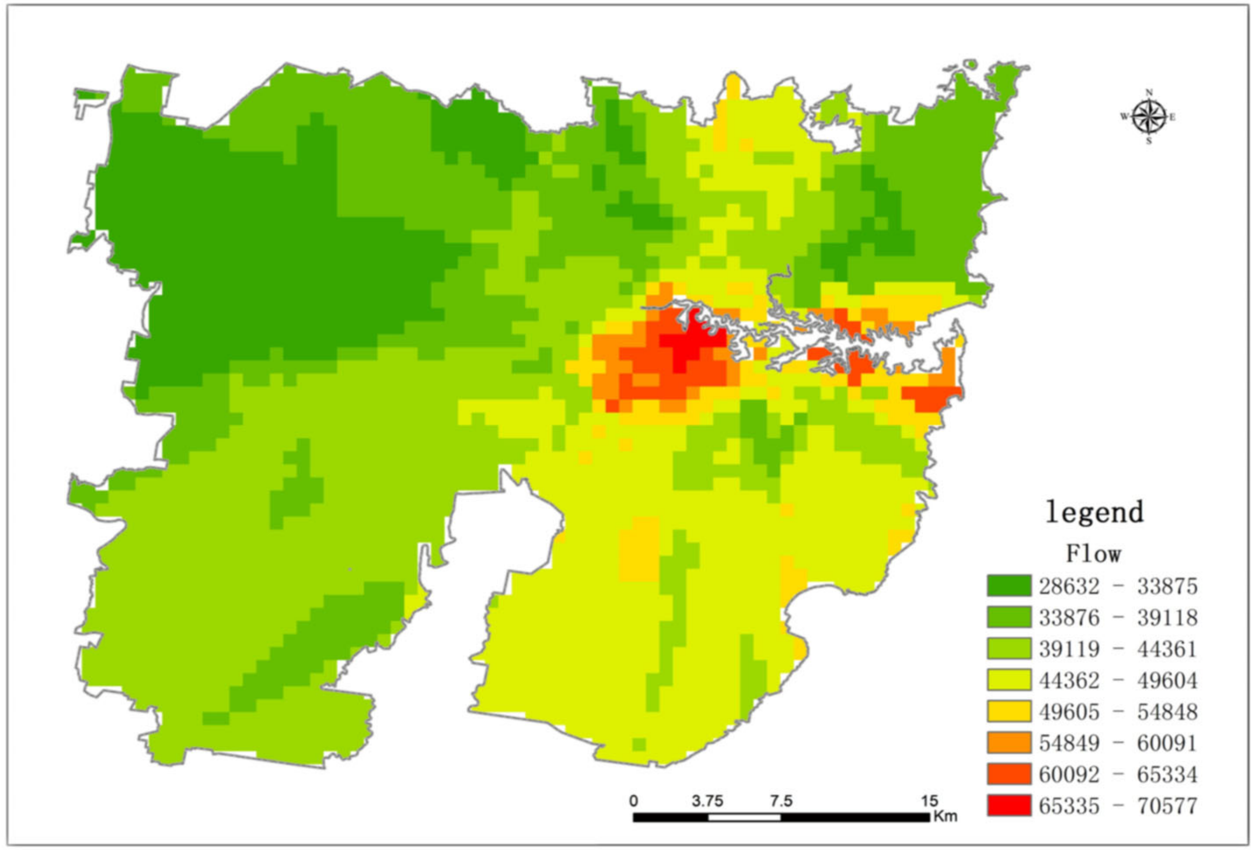
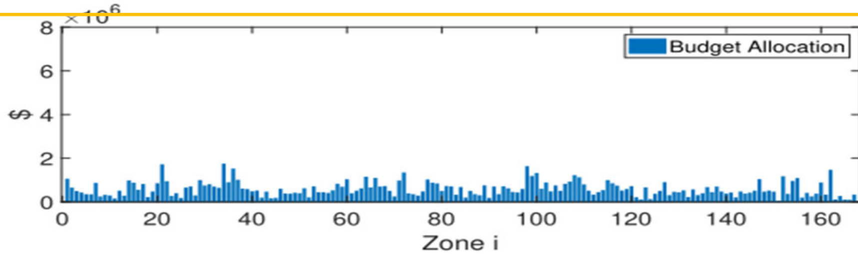
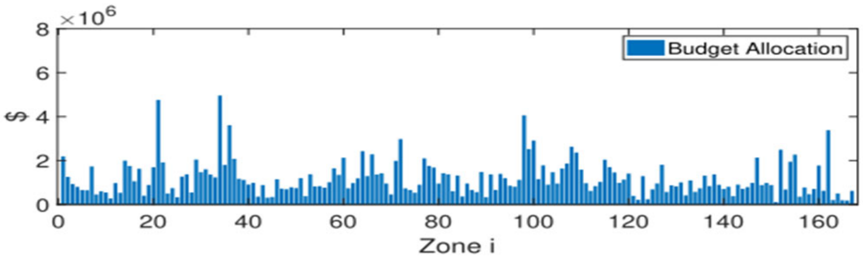


Figure 10. The visualization of prediction results by 164 nodes across Sydney

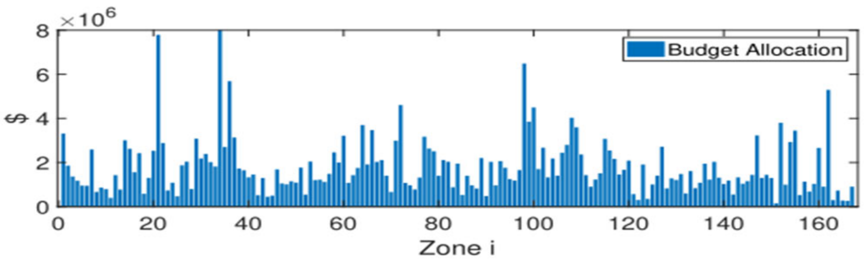
Experiment: The Optimal Strategy of Budget Allocation



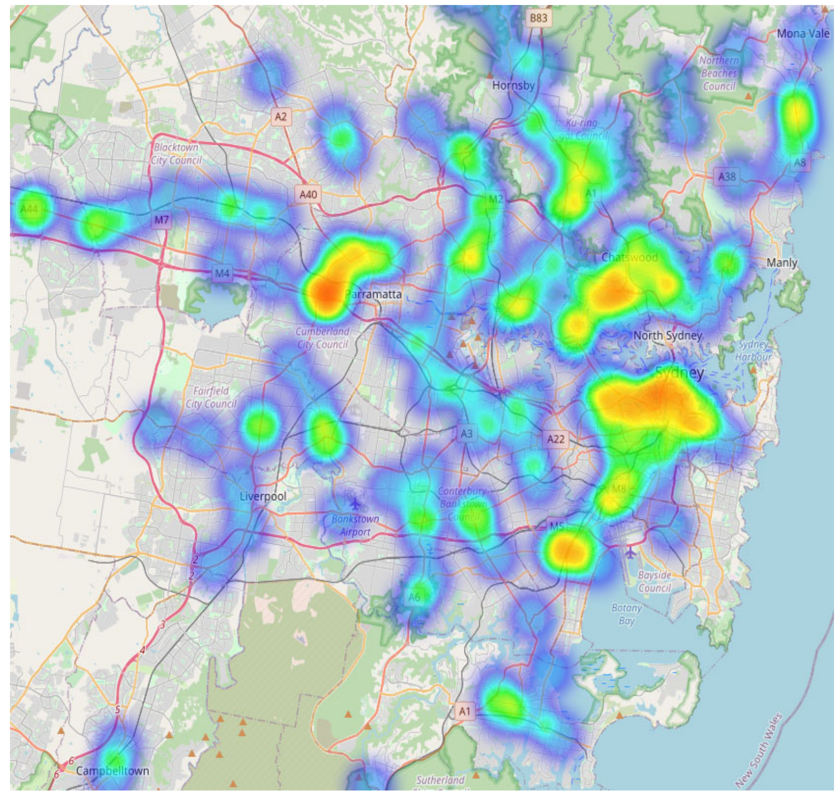
(a) Service provider $m = 1$ with Budget $B_1 = \$100,000,000$



(b) Service provider $m = 2$ with Budget $B_2 = \$200,000,000$



(c) Service provider $m = 3$ with Budget $B_3 = \$300,000,000$



(d) The heatmap of budget across Sydney

Figure 11. The budget allocated by three service providers on 164 locations across Sydney

Experiment: The Optimal EV charger allocation with & without local distribution network constraints (1)

- ➢ The local distribution network constraints

- ➢ Configuration:
  - 7 transmission substations
  - 35 zone substations
  - 41 transportation nodes

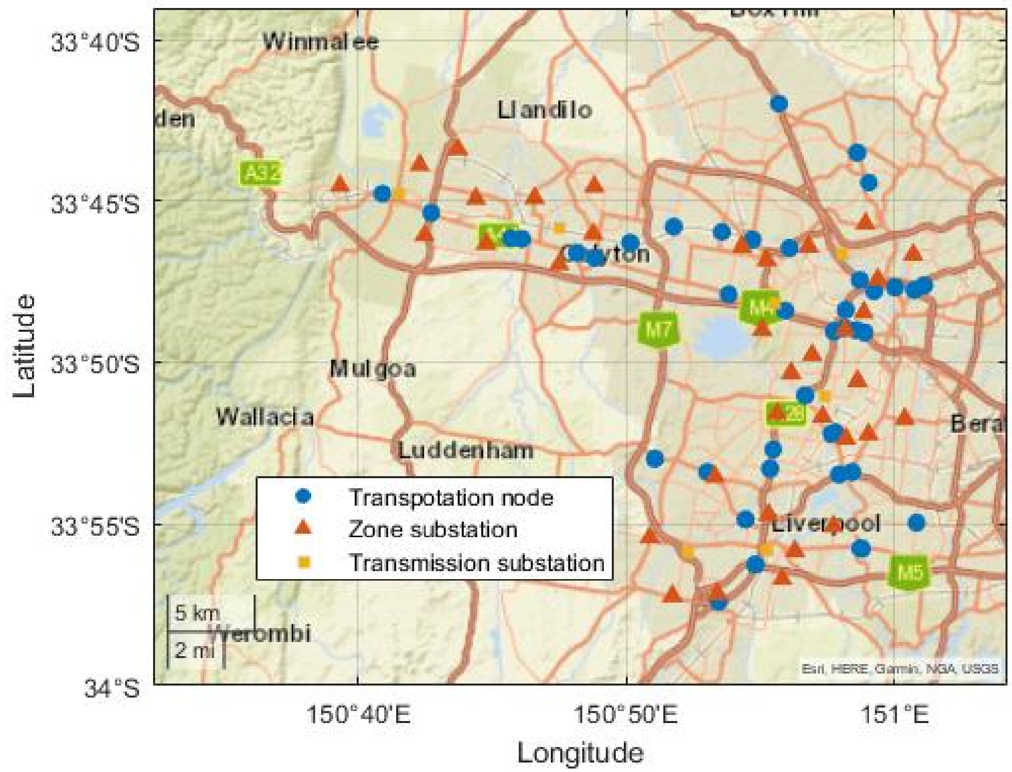
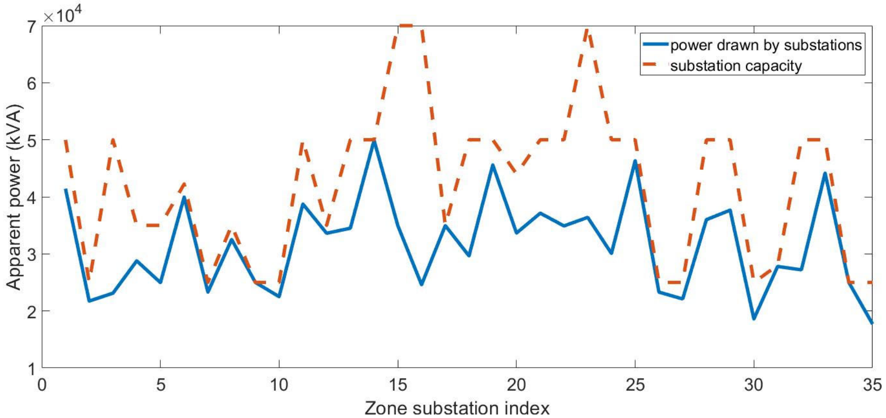
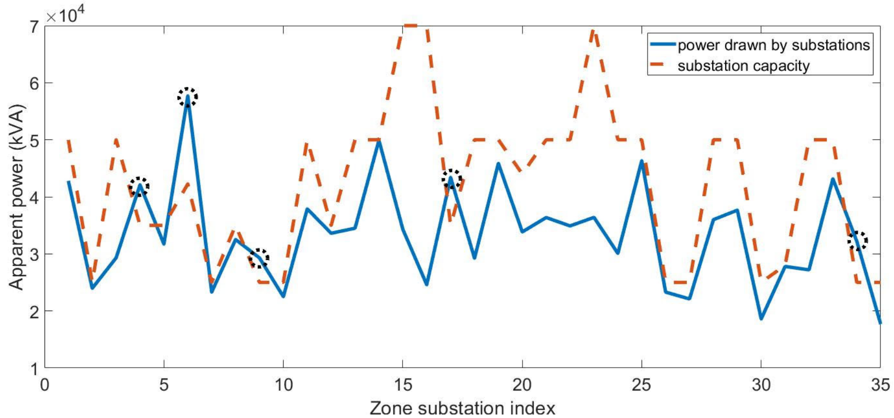


Figure 12. Location of transportation and LDN nodes

Experiment: The Optimal EV charger allocation with and without LDN constraints



(a)



(b)

Figure 13. Substation loads with DN constraints (a) and without DN constraints (b)

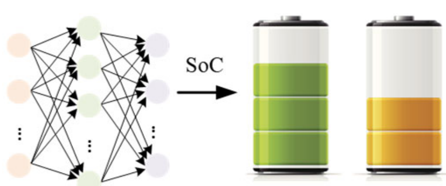
(1)When the planning is conducted with LDN constraints, none of the zone substations exceeded its capacity, meaning the current LDN configuration can support the planned number of charging stations and EV chargers

(2)When LDN constraints are ignored in the planning phase, 5 of the zone substations will have loads that exceed their capacities, meaning the LDN needs to be upgraded to support the planned deployment of EV chargers by the three service providers.

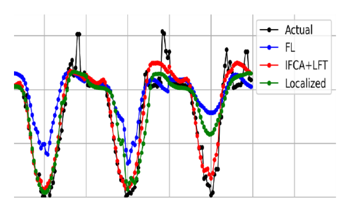
EV Charging Management Strategies

☐ intelligent coordination system for EV charging

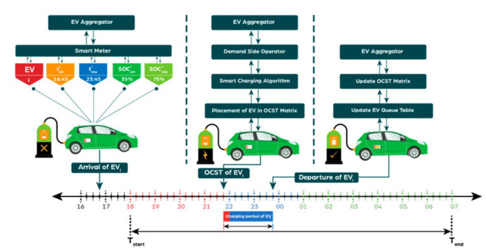
1. Deep learning based SoC estimation method that adapt to different environment condition
2. Accurate market price prediction method for energy market opportunities
3. Fair and efficient pricing mechanism design for local EV charging
    - Lowering rates or rewarding charging of preferred patterns
    - Setting rates or rewards at different levels for different EV owner groups
    - Optimal and interactive charge waiting time control for clients without causing grid stability problem
4. Optimal coordination strategy for EV charging
    - Dynamic charging schedule
    - Mobile app for EV charging and sharing navigation
5. Profit-maximization V2G communication interface – prosumer opportunity
    - Q-learning network control algorithm



SoC estimation



Electricity price prediction



Coordinated EV charging

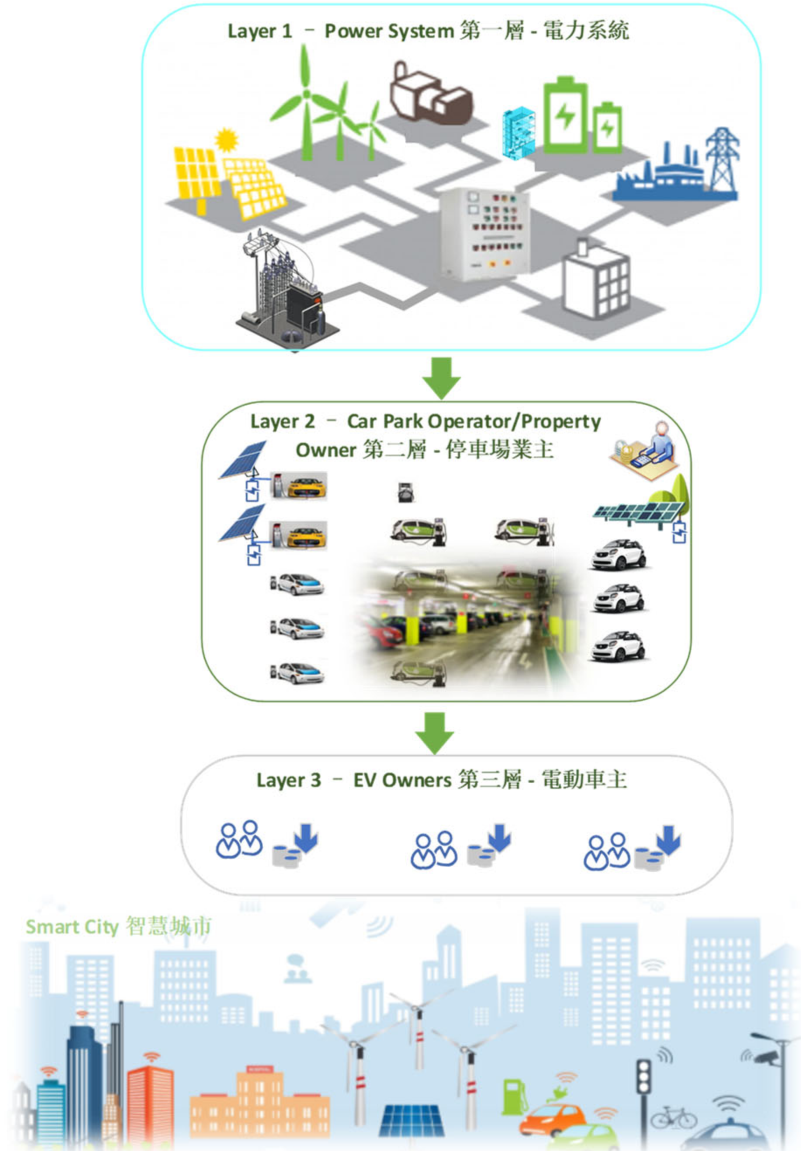
EV charging management eco-system (HK)

System - It will enable system operators to effectively manage the power grid to host large number of EVs without blackout while enjoying capital deferral benefits;

Community - It provides tools for car park operators with EV charging facilities to avoid potential loss of electricity; and

Individuals - It provides optimal charging strategies for EV owners to save on charging while be assured of sufficient battery charge to drive.

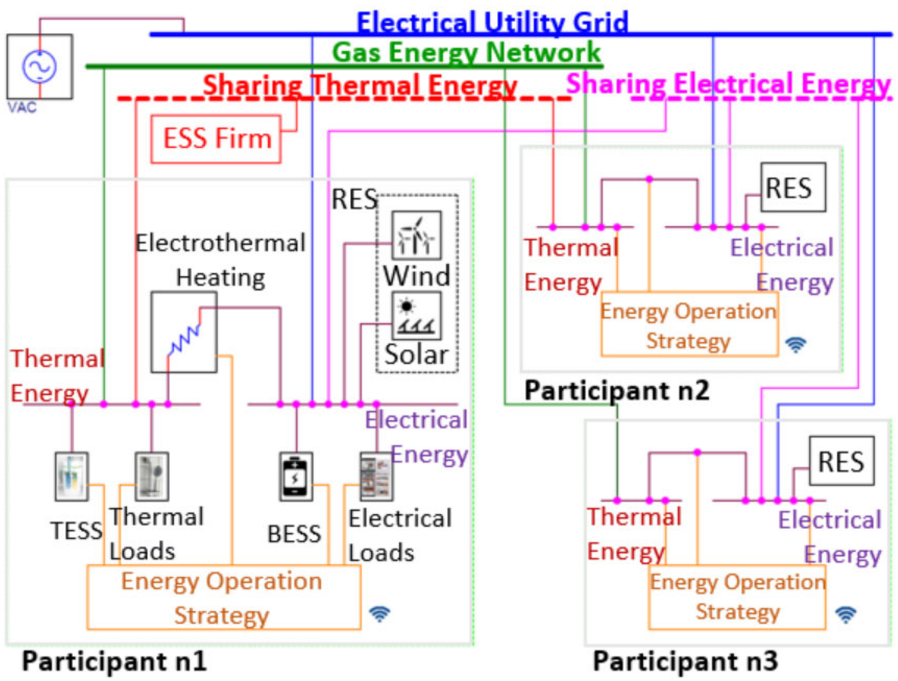
Source: CAFEA, Acknowledgement HK Green Tech Fund



Energy Sharing – Per-Use-Share Rental Strategy

Per-use-share rental strategy in an energy market

- Sale model: customers buy & own energy storage system (ESS) devices.
- Per-use-share rental strategy: customers need ESS but can't or wouldn't like to afford/buy.
- The rental strategy is profitable when the customer's reserve is higher than rent.



- A collaborative shared electric vehicle planning strategy in coupled power distribution and transportation network to assist in strategic and tactical decision making.

- Objective: To minimize overall investment cost, energy losses, and car sharing operation waiting cost while maximizing the satisfied travel demand via optimizing the deployment and sizing of charging station location

EV Sharing

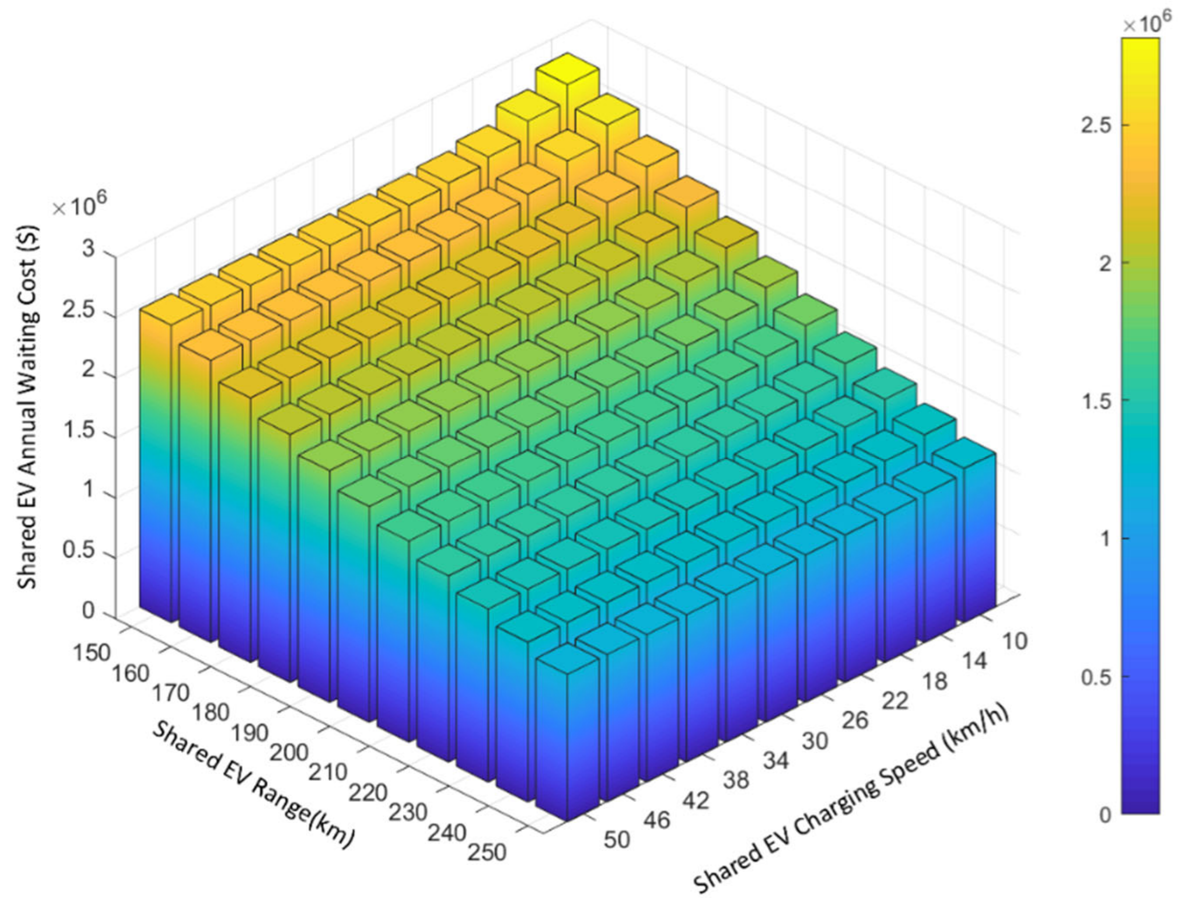
Benefits

- Lower energy usage and emission profile
- Less overall life-cycle energy consumption
- Higher driving intensity
- More efficient use of urban space
- Reduce traffic congestion
- Lower cost than private transportation

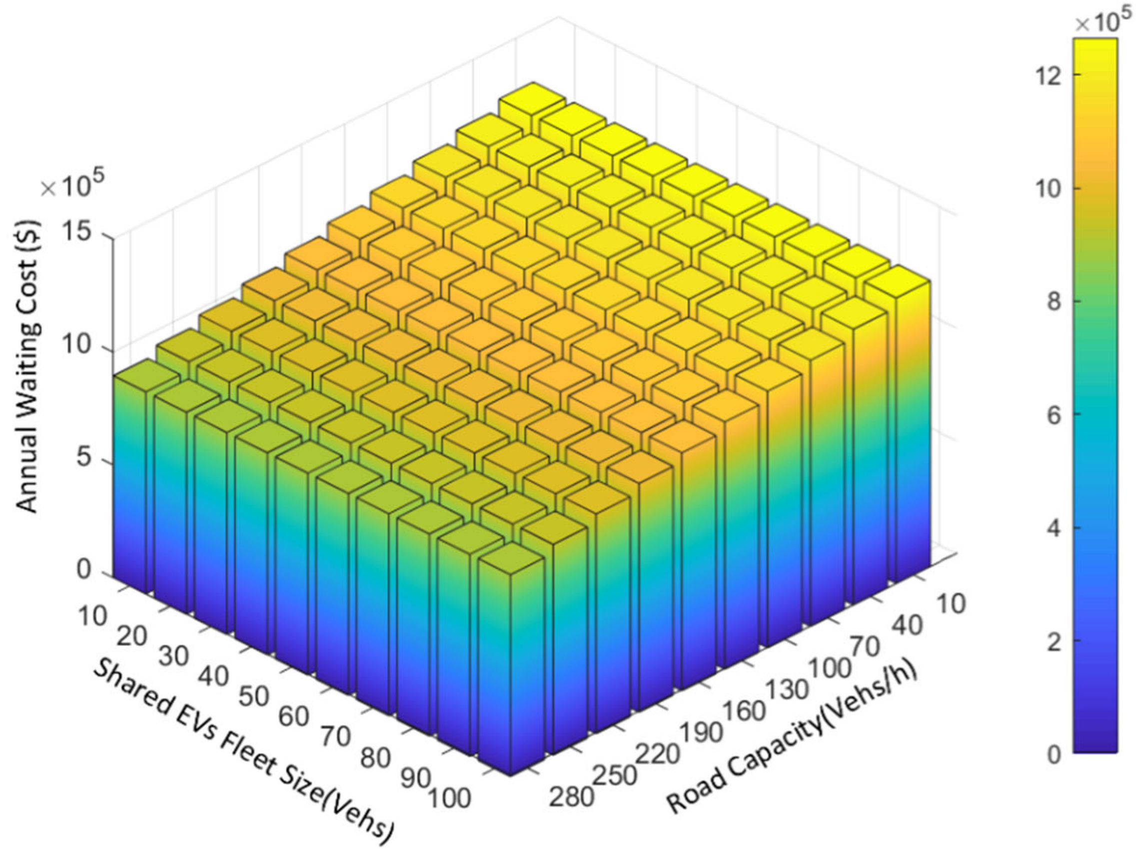
Challenges

- Charging infrastructure
- Siting parking and charging locations
- EV fleet size
- Stochastic travel demand
- Dynamic Routing and Repositioning Problem (DRRP)
- Charging load impact

Sensitivity Analysis: EV Range and Charging Speed



Sensitivity Analysis: EV Fleet Size and Road Capacity



Conclusions – Grid Impact & the way forward

- When EV charging is shifted outside peak times, there is the potential for a new peak to be created with sufficient EV penetration projected towards the end of the assessment period.
- It will be critical to establish charging schemes which spread the charging over the overnight period by either:
  - Controlling charge start times to achieve greater diversity (as per the off peak controlled scenario) or
  - Controlling or encouraging charging rates to be kept at the minimum level possible (as per the constant charging scheme)
  - Controlling charging rates to respond to network signals (as per the smart charging scheme)
- The effects of these charging schemes have been explored for specific feeders within the network considered likely to be the most impacted by electric vehicle charging, with smart charging found to be the like most effective approach in the longer term.
- The shared EV operational waiting cost is one of the influential factors on overall investment profile.
- Sensitivity analysis highlights direct relation between parameters from transportation sector such as fleet size, shared EV range, and road capacity.

Thank you

References

- V.H. Fan, S Wang, K Meng, ZY Dong, “Optimal shared mobility planning for electric vehicles in the distribution network”, IET GTD 13(11) 2019, pp.2257-2267
- C. Li, Z. Dong, G. Chen, B. Zhou, J. Zhang and X. Yu, "Data-driven Planning of Electric Vehicle Charging Infrastructure: A Case Study of Sydney, Australia," IEEE Transactions on Smart Grid, doi: 10.1109/TSG.2021.3054763
- LL Sun, J Qiu, X. Han, X. Yin and ZY Dong, “Capacity and energy sharing platform with hybrid energy storage system: An example of hospitality industry, Applied Energy, 280 (2020) 115897
- https://about.bnef.com/new-energy-outlook/
- https://electricvehiclecouncil.com.au/wp-content/uploads/2020/08/EVC-State-of-EVs-2020-report.pdf
- http://www.rms.nsw.gov.au/about/corporate-publications/statistics/traffic-volumes/aadt-map/index.html#/?z=10

Acknowledgement

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE 30 1991-2021

CAFEA Smart City

SynCo Global