University of Technology Sydney

Australian Energy Market Operator

How will electric vehicles affect traffic congestion and energy consumption: an integrated modelling approach

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Introduction

Challenges:

- How to evaluate the impact of EV station location on charging times?
- How will traffic congestion affect the EV charging needs?
- How to model energy consumption and traffic behaviour together?

*EV – Electric vehicle

Factors affecting EV adoption

1. EV charging station:
- Number of charging plugs [n]
- Charging plug power [kW]
- Number of charging stations

2. Electrical grid:
- Energy substation capacity [kW]

Adoption of electric vehicles (EVs)

3. Electric vehicles:
- EV battery size [kWh]
- Average travel distance [km]
- EV station traffic flow [veh/h]

4. Service:
- Mean waiting time [h]
- Total time spent at the charging station [h]
- Mean queue length [n]

Contributions

1) We propose a novel integrated **traffic micro-simulation** and **queue behavioural model** for EV charging.

2) Modelling of the **queue charging impact** around existing EV charging stops.

3) Exploration of hypothetical **future demand scenarios** and their impact on EV charging behaviour.

Integrated Bi-level Framework

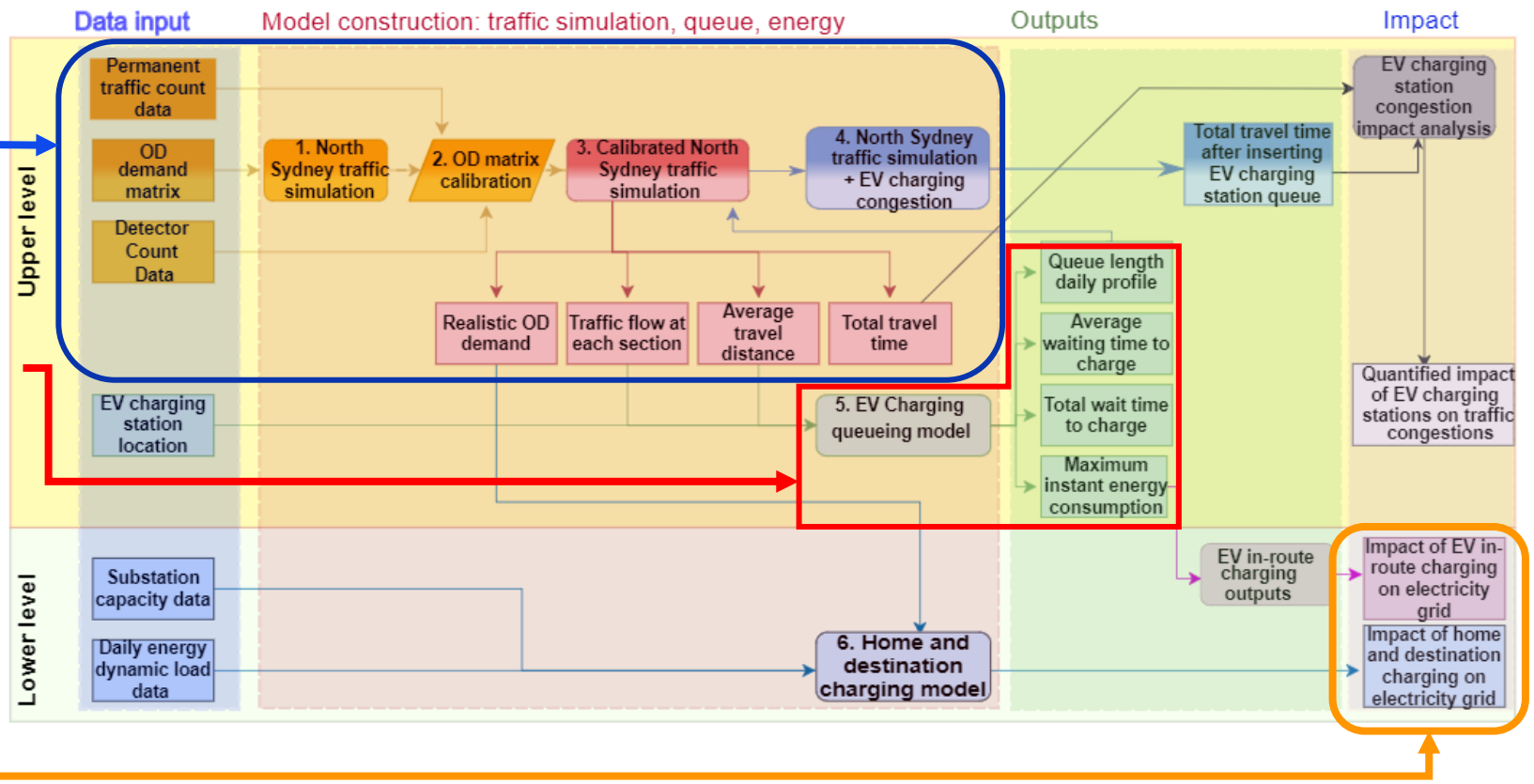
Architecture of the bi-level framework:

a) A dynamic micro-scale traffic simulation

b) A queue model for energy fast-charging usage

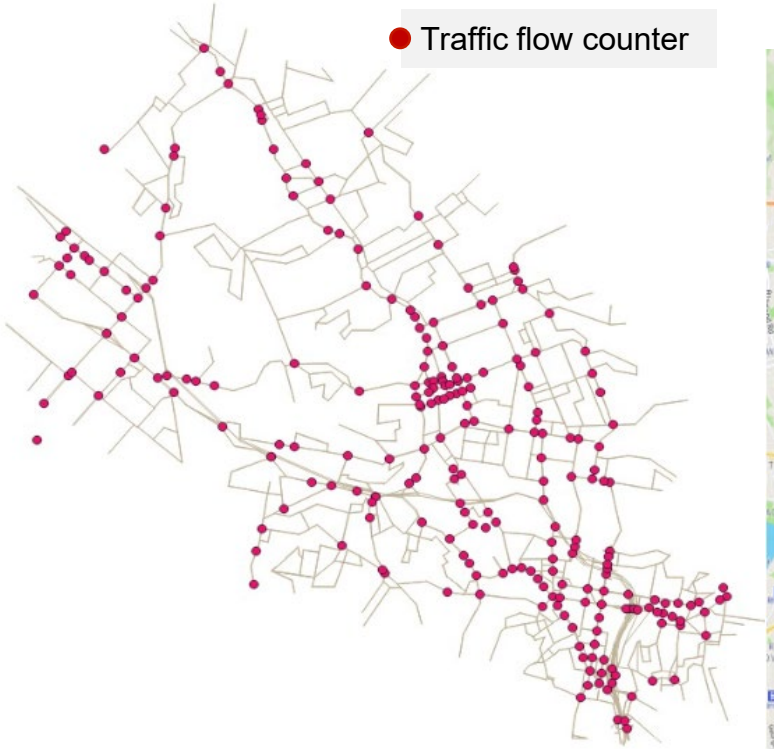
c) Energy fast-charging model

d) Impact evaluation



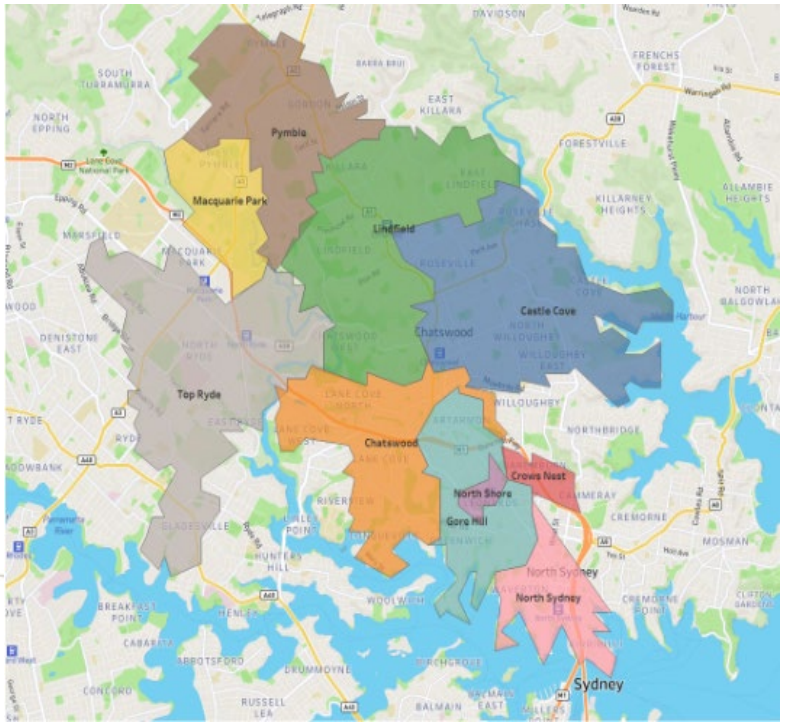
Available Data Sets

Traffic flow counters



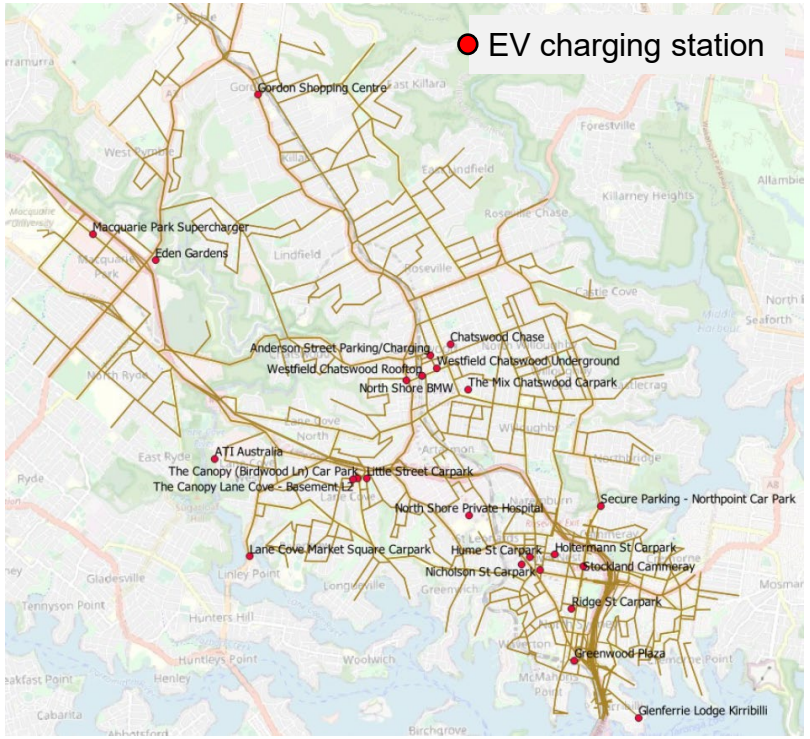
41 permanent traffic count stations

Energy substation zones



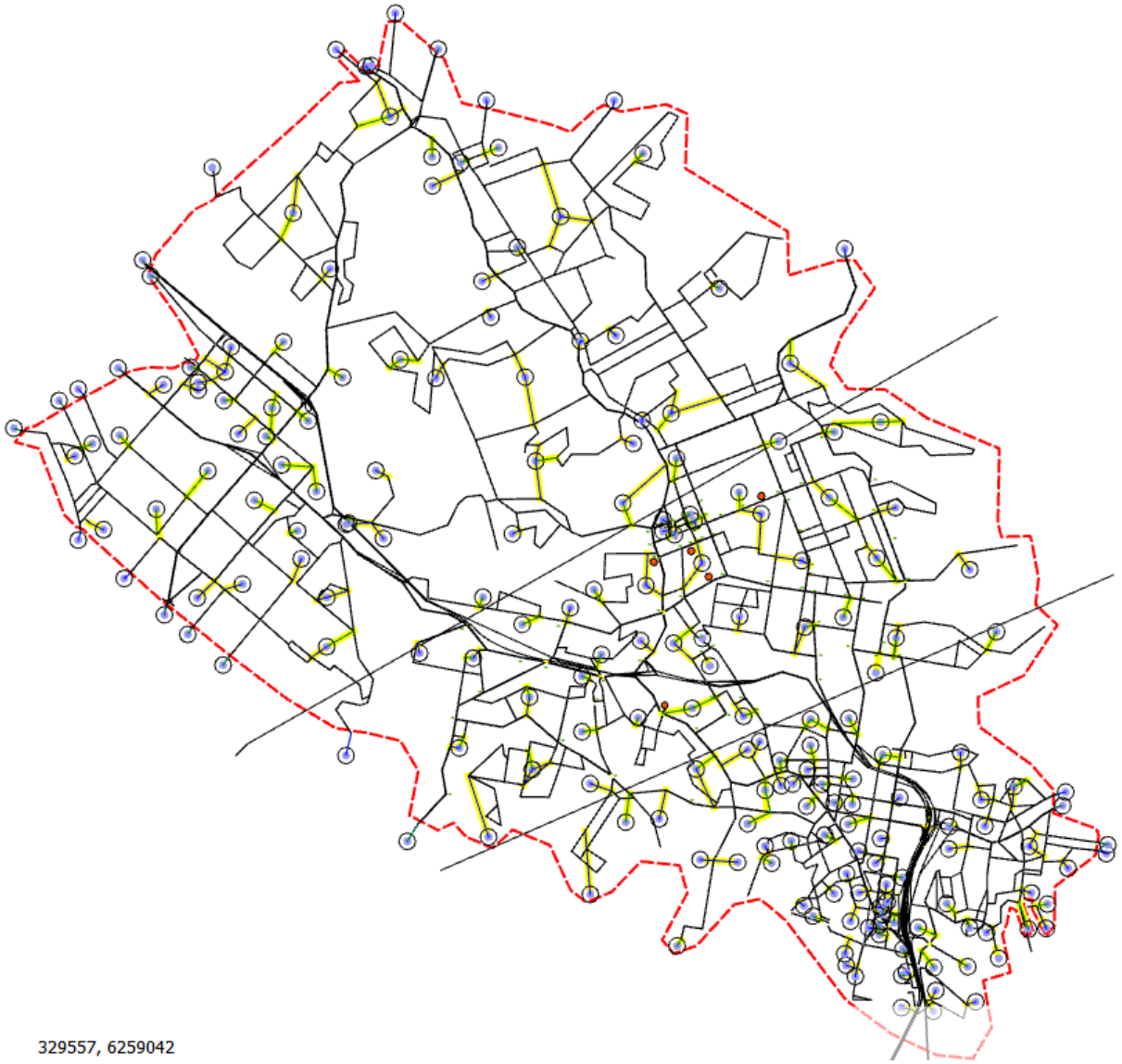
10 energy substations

Electric vehicle charging stations



25 EV charging stations

North Sydney traffic simulation model (NSTM)



The NSTM model:

- The daily trips of almost 100,000 people

(according to 2016 Australian Census data)

- 25 EV charging stations

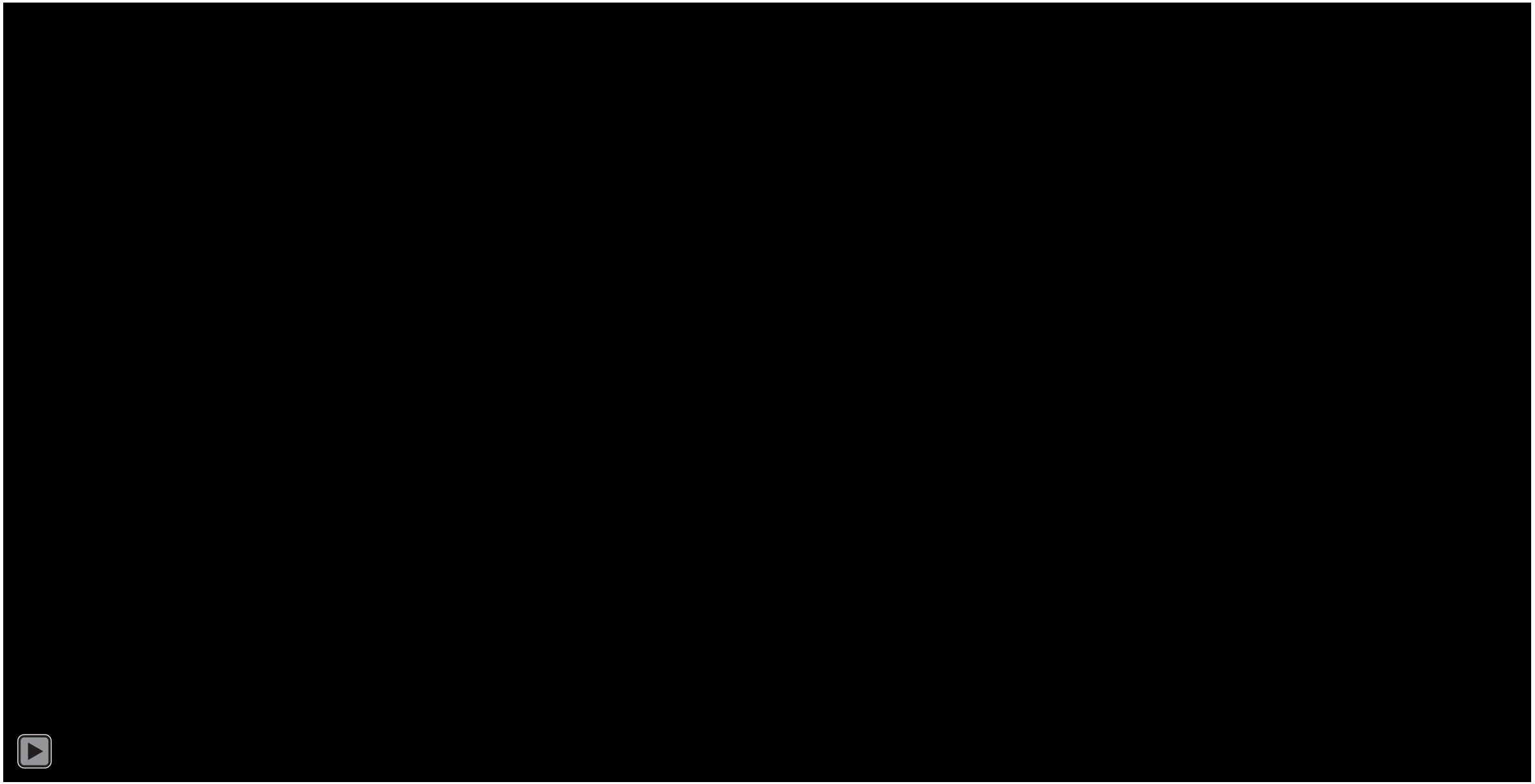
- 41 permanent traffic count stations

- 240 SCATS controlled intersections

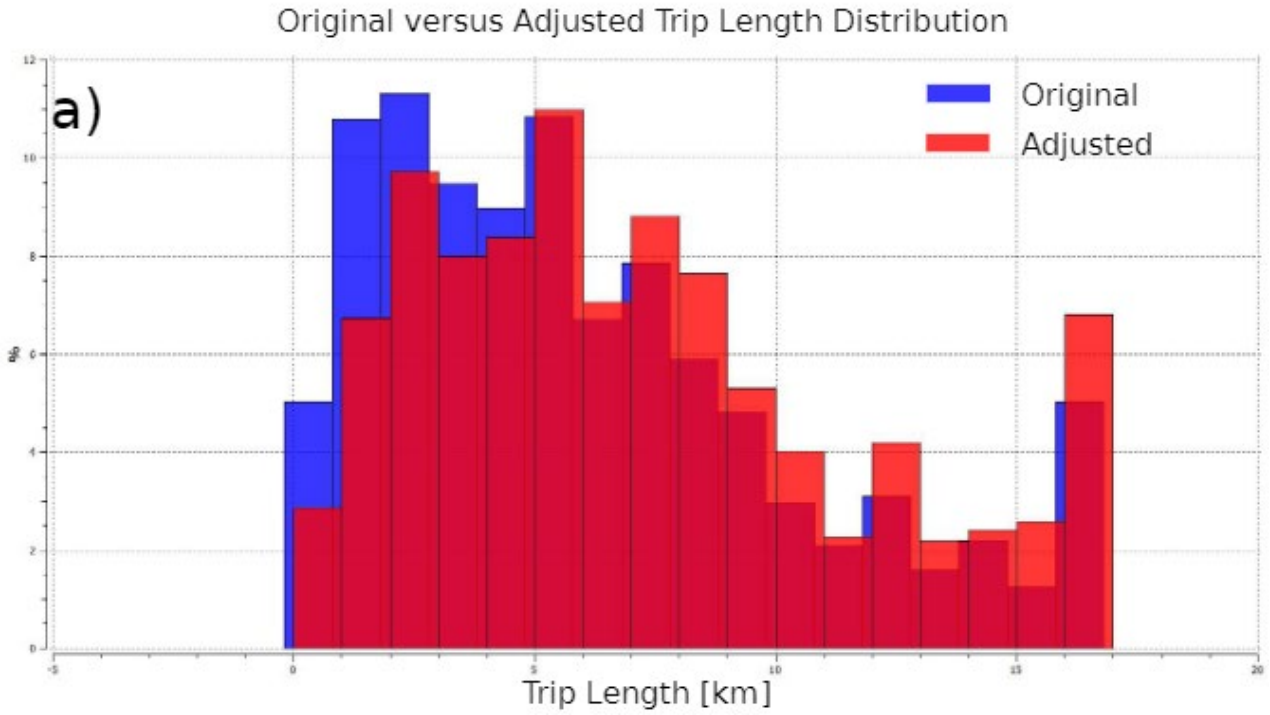
- 1,919 traffic flow detectors

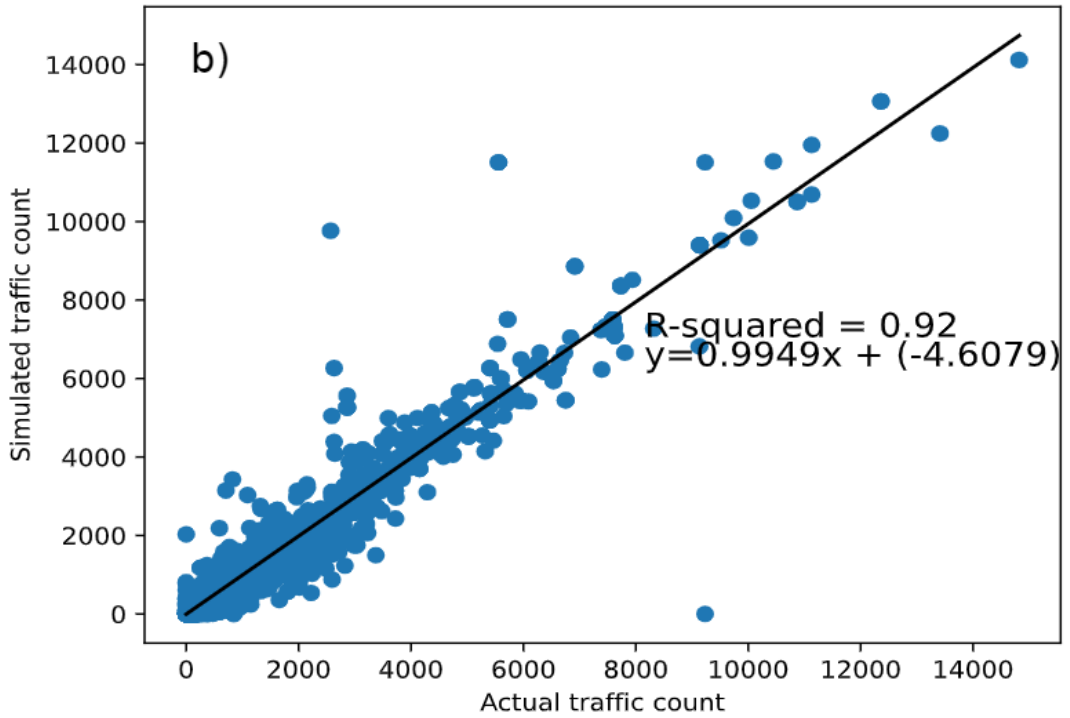
- 2,750 road sections.

Simulation



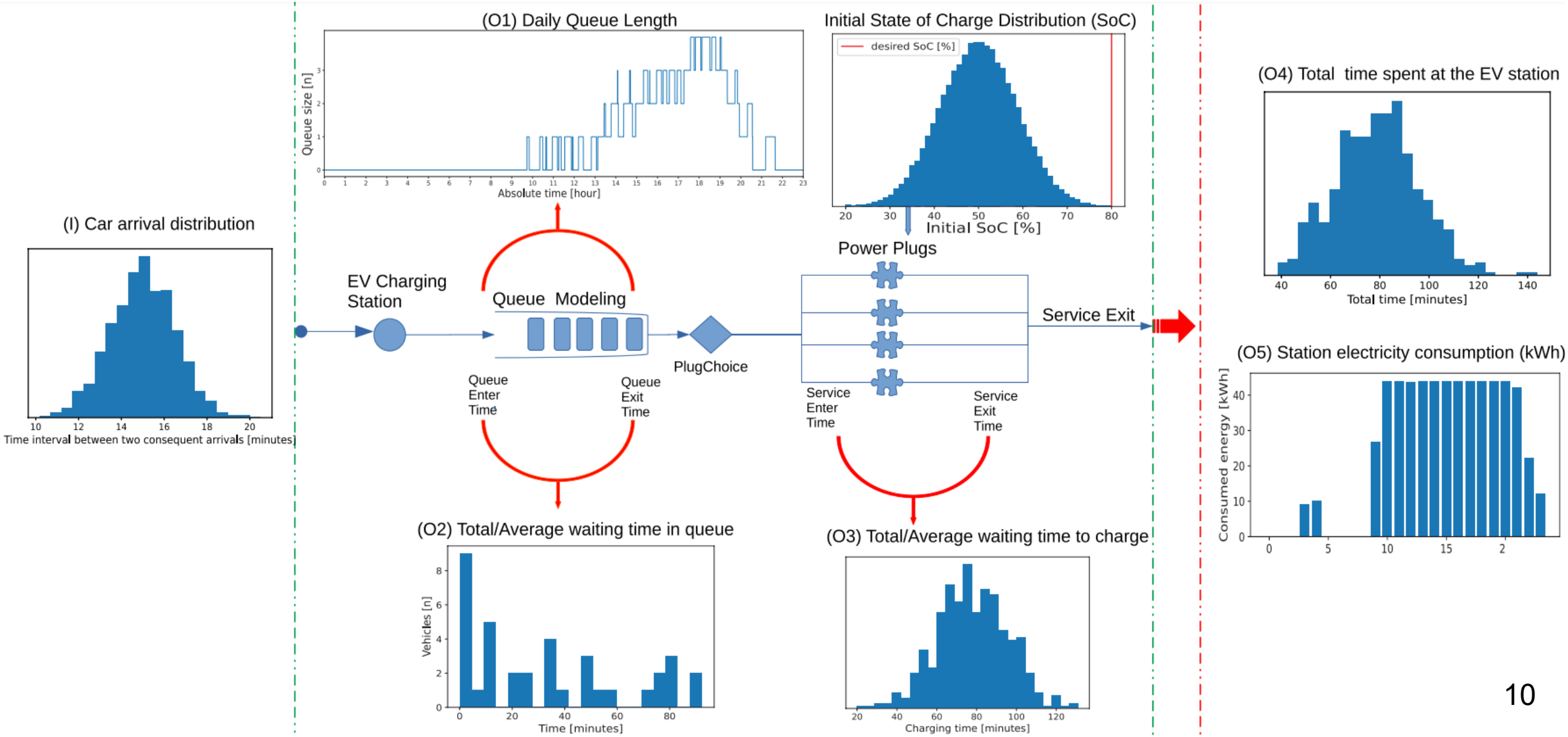
NSTM validation



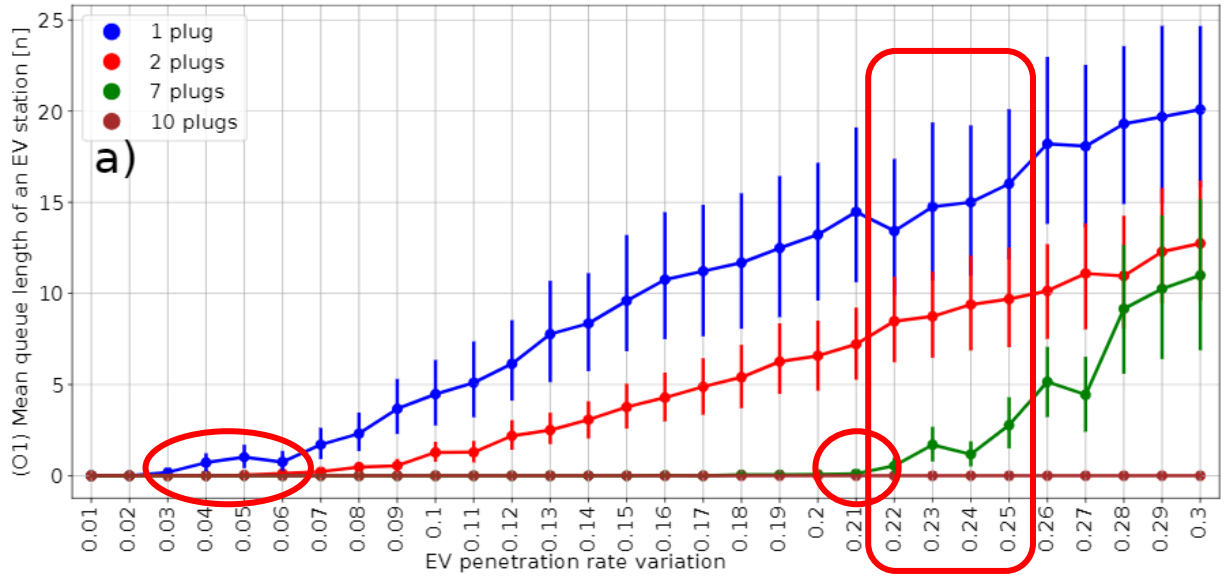


Validation of NSTM model for the AM peak via a) TripLength Distribution and b) R2=0.92 metric.

Queue model


(O1) Daily Queue Length
Queue size [n]
Absolute time [hour]
Initial State of Charge Distribution (SoC)
desired SoC [%]
Initial SoC [%]
(O4) Total time spent at the EV station
Total time [minutes]
(I) Car arrival distribution
Time interval between two consequent arrivals [minutes]
EV Charging Station
Queue Modeling
PlugChoice
Power Plugs
Service Exit
Queue Enter Time
Queue Exit Time
Service Enter Time
Service Exit Time
(O5) Station electricity consumption (kWh)
Consumed energy [kWh]
(O2) Total/Average waiting time in queue
Vehicles [n]
Time [minutes]
(O3) Total/Average waiting time to charge
Charging time [minutes]

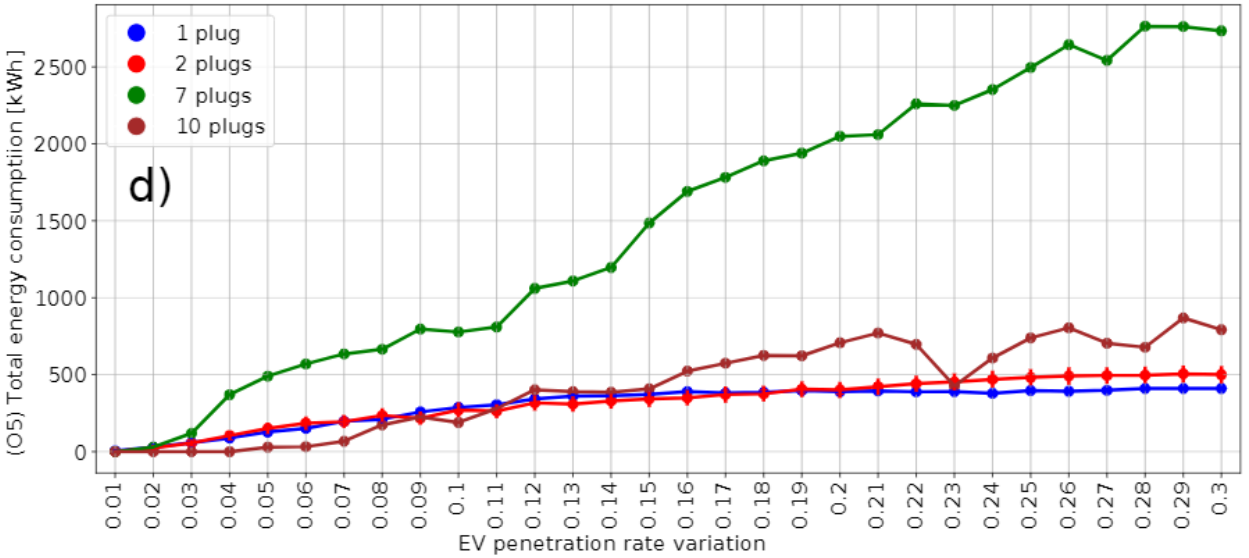
Charging impact results



The number of plugs significantly affects the **mean queue length**.

The waiting times to charge can be significantly reduced by adding **extra charging plugs**.

Increase in the number of plugs greatly increases station ability to service at higher EVp rate.



High energy consumption in congested areas (because of high EVp).

Mean waiting time vs queue length of EV stations across various EV% rates

Mean waiting time for 1-plug stations increases significantly with EVp.

Adding extra plugs significantly reduces waiting time and queue length.

7-plug stations maintain waiting times to charge below 2h until EVp equals 0.27%.

Total energy consumed at the station vs Total time spent by EVs across various EV% rates

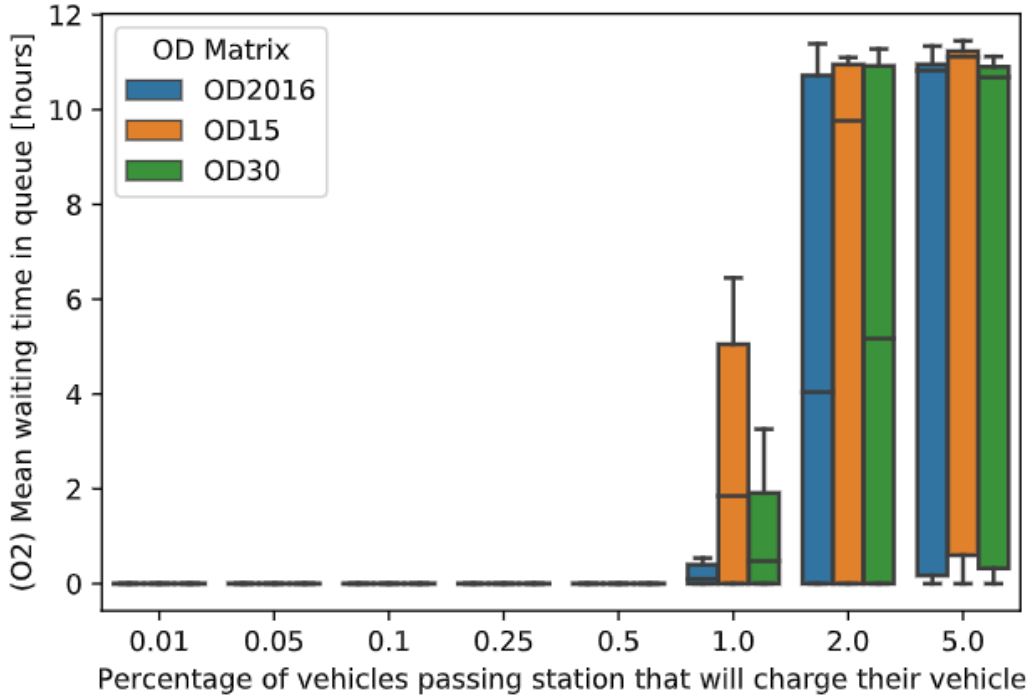
(Evp=0.04%)
Energy consumption for 1-plug stations reaches the station capacity limit, leading to queue overflow and increased total time spent.

(Evp=0.06%)
Several 2-plug stations reach the energy capacity limit.

(Evp=0.25%)
3-, 4- & 7-plug stations charge below 2h limit.
(Evp=0.27%)
Most 7-plug stations reach the limit.

(Evp=1%)
Even 10-plug stations reach the station capacity limit, leading to queue overflow and increased total time spent.

Queue waiting time at different EV_p [%].



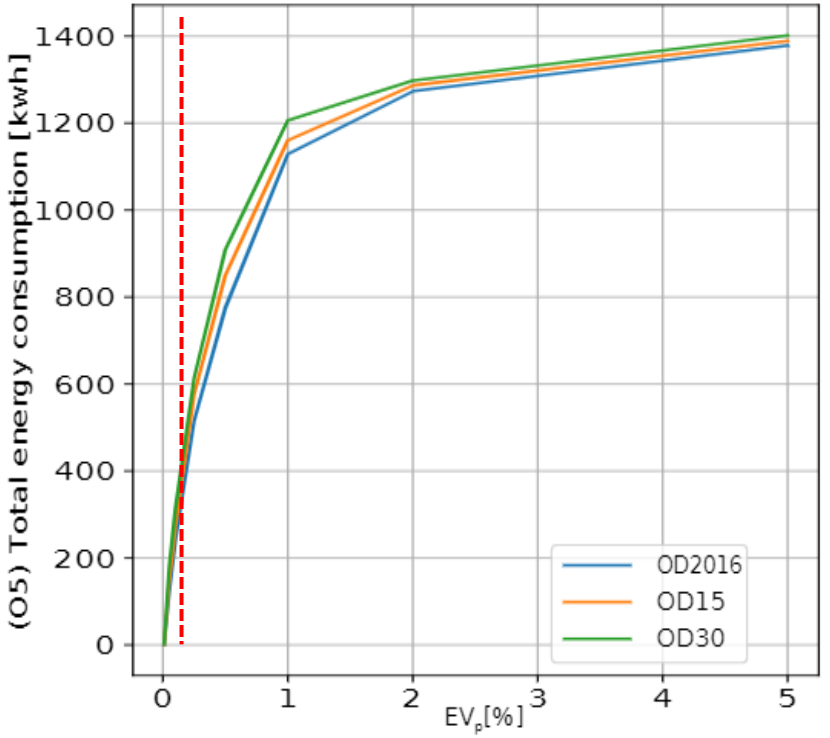
Mean queue variation for 10-plug EV stations

- 10-plug EV stations can supply the charging demand up to 1% of EVp
- When an EV station reaches its capacity, then the waiting time spikes exponentially.
- Increasing traffic demand over upcoming years by 15 and 30 percent can have a significant impact on queueing at the charging station.

Energy consumption at different EV_p [%].

EV rate variation for OD2016	0.01	0.05	0.1	0.25	0.5	1	2	5
(O1) Mean queue length of an EV station [n]	0	0.27	1.53	8.27	17.74	30.97	48.22	66.36
(O2) Mean waiting time in queue at an EV station [hours]	0	0.28	1.44	6.71	13.44	22.58	29.69	38.83
(O3) Mean service time to charge at an EV station [hours]	0	0.18	0.34	0.65	0.82	0.93	1.01	1.1
(O4) Total time spent overall at an EV station [hours]	0	0.46	1.78	7.35	14.26	23.51	30.7	39.93
(O5) Total energy consumption of an EV station [kWh]	0.24	115.59	232.92	538.75	795.28	1127.38	1292.76	1408.49
(O6) Maximum recorded queue length of an EV station [n]	0	0.86	4.22	19.48	37.72	57.41	82.83	98.07
(O7) Maximum waiting time in queue at an EV station [hours]	0	0.71	3.72	15.56	28.74	42.2	49.68	57.17
(O8) Maximum time spent overall at an EV station [hours]	0	1.26	4.58	16.89	30.16	43.41	50.86	58.47
(O9) Maximal energy consumption of an EV station [kW]	0.04	6.26	11.41	26.23	39.28	48.87	55.46	60.69

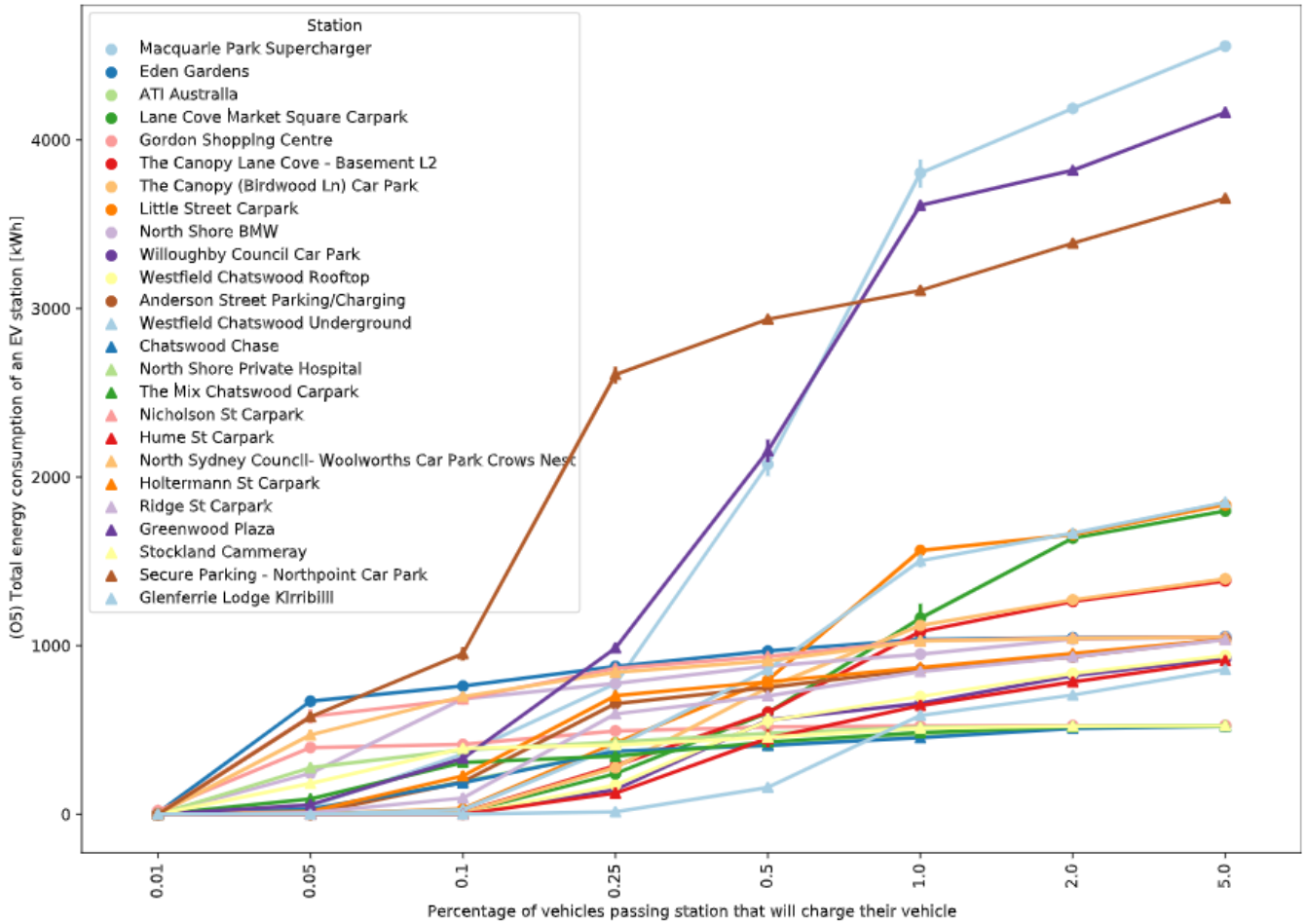
We set the maximum acceptable mean waiting time to be 2h.
At around 0.1% EVp, all charging stations reach their capacity.



Total energy consumption across EV stations

The total energy consumed at EV station becomes limited by:
- the charging station setup (number of charging plugs, power of plugs)
- the station service performance

Energy consumption of all stations vs EV_p [%]



The total energy consumed at an EV station is defined by:

- the charging station setup

(number of charging plugs, power of plugs)

- the station service performance

- the traffic flow around the EV station

- the EVp rate

Conclusions

- We propose an **integrated bi-level framework** of dynamic traffic modelling, data-driven queue and energy modelling.

- We evaluate the **EV impact** on both the traffic network and the energy consumption of the studies area.

- We reveal existing **limitations of the EV charging infrastructure** which would not be able to handle even slight increases of EV rates.

- We observe significant travel time and waiting time degradation **for larger EV penetration rates** at each station level.

Thank you!

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