

On Simulation and Optimization of Freeway Network Operations

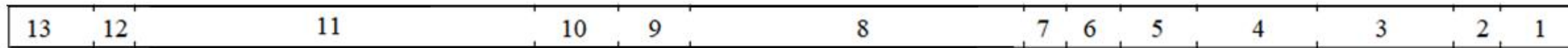
B. Wiwatanapataphee & Yong Hong Wu
Curtin University of Technology



Progress from last PSG meeting

- An Overview
- Simulation and calibration of traffic flow model
- Implementation of the new KWN Freeway configuration
- Data Analysis – link traffic prediction by BAM-LSTM
- Optimization of Freeway Traffic Flow via Ramp Metering by CTM

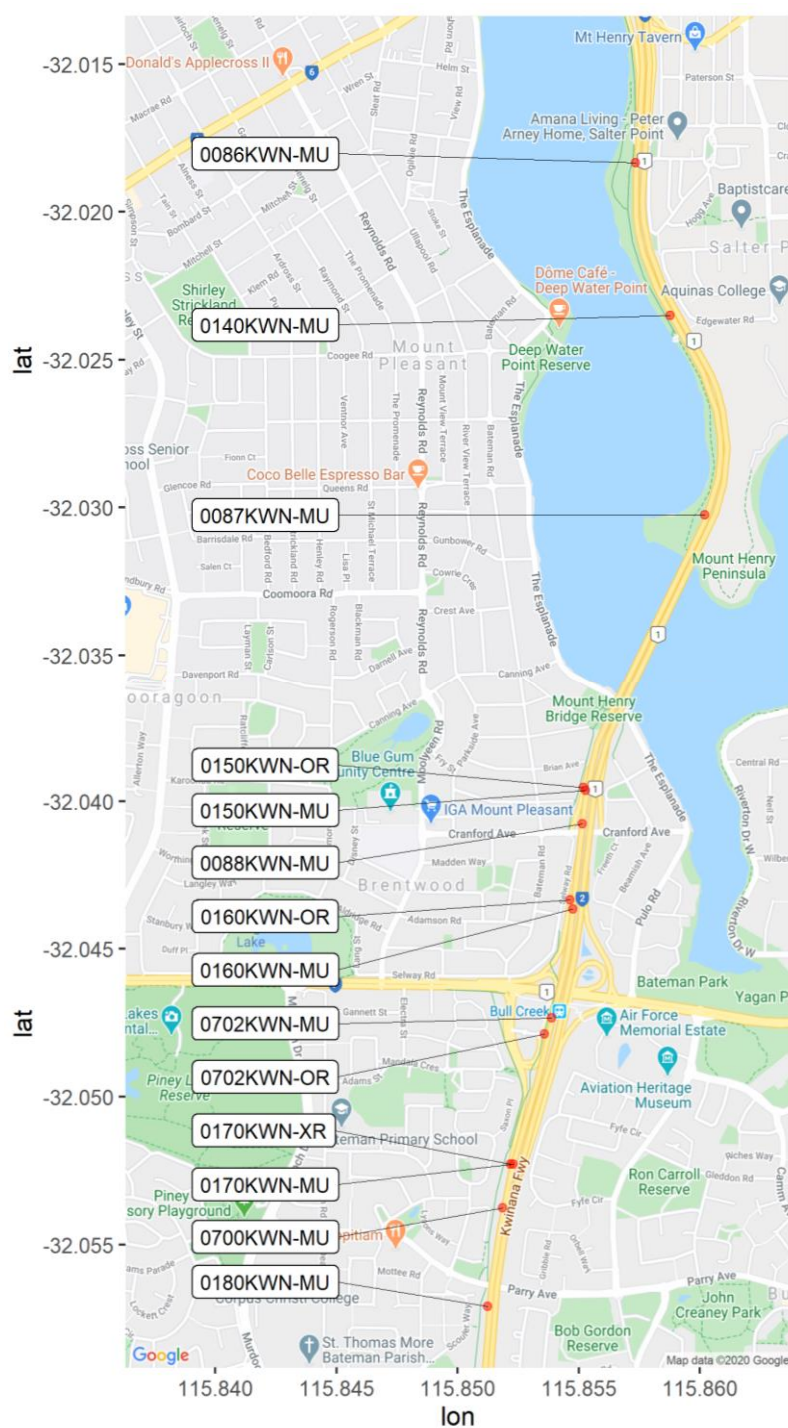
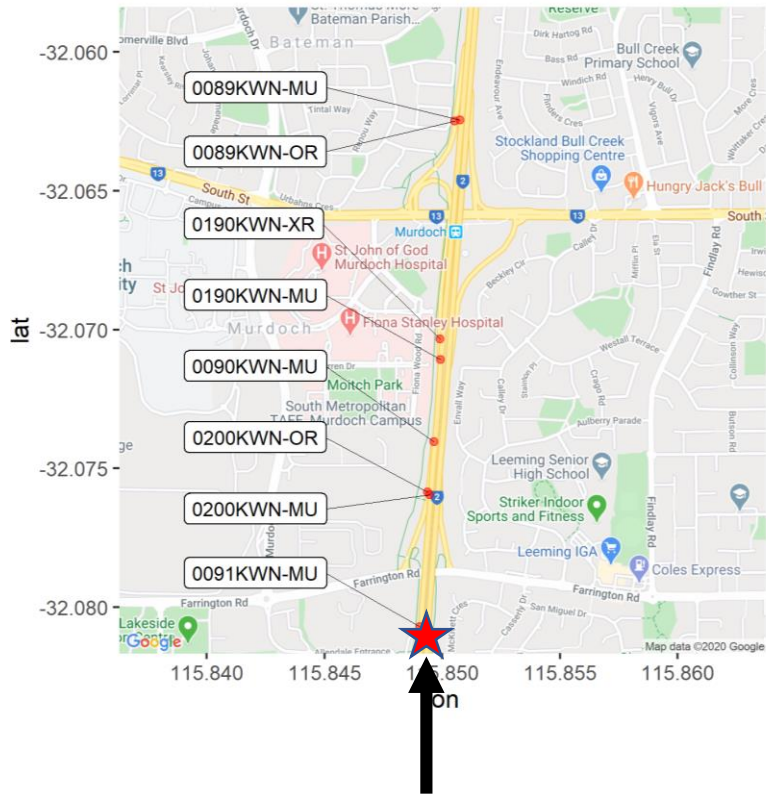
1 Simulation and calibration of traffic flow model

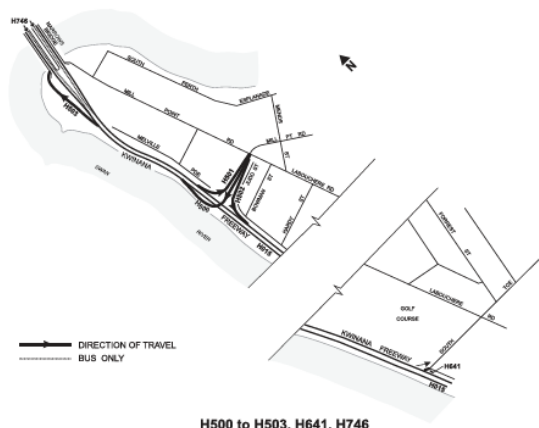


Study region Kwinana Freeway from Farrington RD to Narrow Bridge about 13 kms consisting 13 sections with 8 on-ramps, 4 off-ramps and 9 bottlenecks .

DATA 31 October 2018 (1) 14 NPI data; (2) 156 Detector lane data

I. Updated network model : Kwinana Fwy Network with 156 Detectors & 14 NPI links

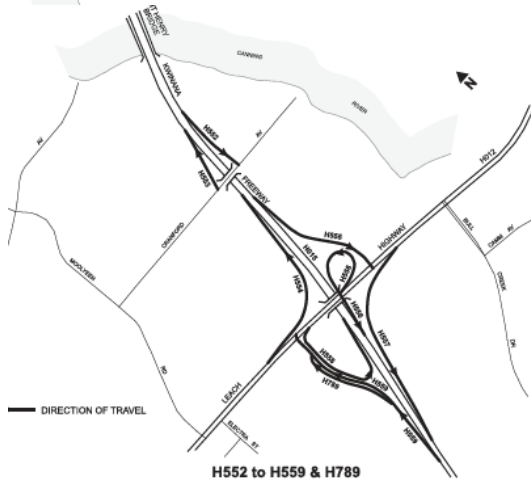




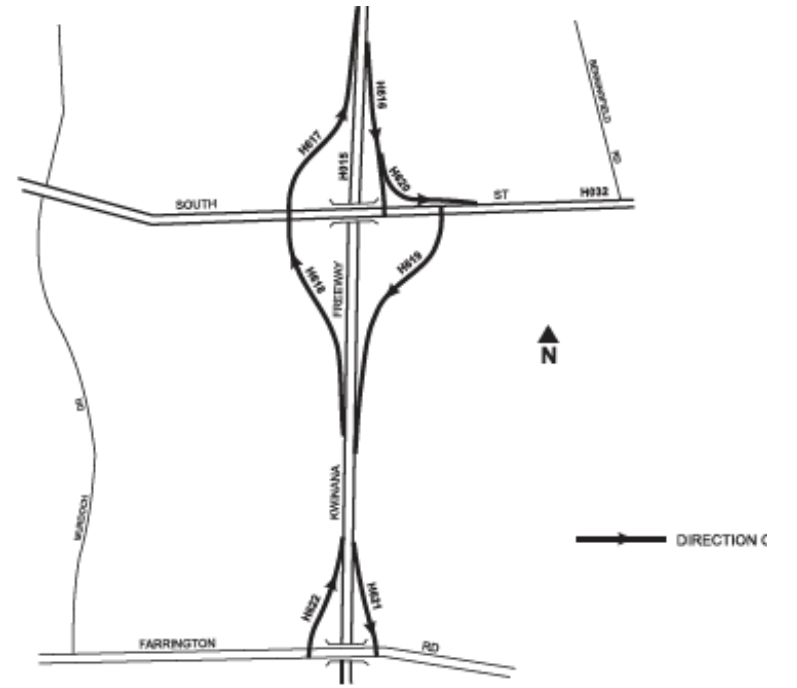
H500 to H503, H641, H746



H544 to H551



H552 to H559 & H789



H616 to H622

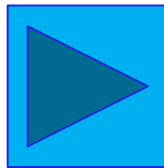


NPI LINK NPI LINK NAME

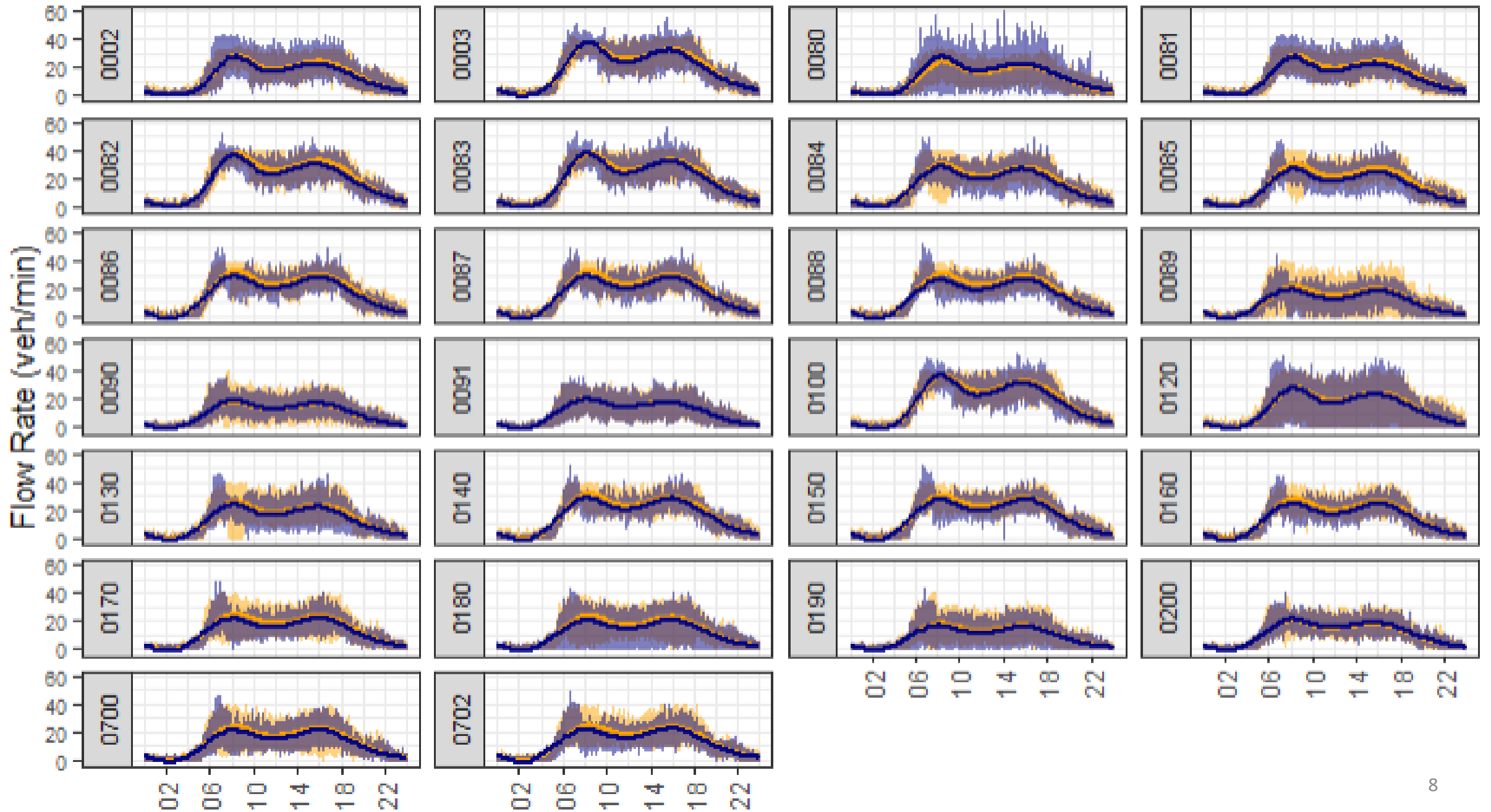
- 1 Kwinana Fwy NB between Kwinana Fwy Nth Bnd H015 Nth Bnd - H018 East Bnd & Kwinana Fwy Nth Bnd H018 W
- 2 Kwinana Fwy NB between Farrington Rd On - H015 Nth Bo & H015 Nth Bound - South St Off
- 3 Kwinana Fwy NB between Kwinana Fwy Nth Bnd H018 West Bnd - H015 Nth Bnd & Farrington Rd On - H015 Nt
- 4 Kwinana Fwy NB between H015 Nth Bound - South St Off & South St On - H015 Nth Bound
- 5 Kwinana Fwy NB between South St On - H015 Nth Bound & H015 Nth Bound - Leach Hwy Off
- 6 Kwinana Fwy NB between H015 Nth Bound - Leach Hwy Off & Leach Hwy West Bound On - H015
- 7 Kwinana Fwy NB between Leach Hwy West Bound On - H015 & Leach Hwy East Bound On - H015
- 8 Kwinana Fwy NB between Leach Hwy East Bound On - H015 & Cranford Av On - H015 Nth Bou
- 9 Kwinana Fwy NB between Cranford Av On - H015 Nth Bou & H015 Sth Bound - H548
- 10 Kwinana Fwy NB between H015 Sth Bound - H548 & Manning Rd - H547 On Kwinana Fwy Nth Bound
- 11 Kwinana Fwy NWB between Manning Rd - H547 On Kwinana Fwy Nth Bound & Canning Hwy - H549 On Kwinana F
- 12 Kwinana Fwy NB between Kwinana Fwy (northbound) Bus Ln From Canning Hwy: H013 On To H015 Northbound
- 13 Kwinana Fwy NB between Mill Pt Rd - H500 On Kwinana Fwy Nth Bound & Kwinana Fwy Nth Bound H503 Off -
- 14 Kwinana Fwy NB between Kwinana Fwy Nth Bound H503 Off - Mill Pt Rd & Mitchell Fwy Nth Bound

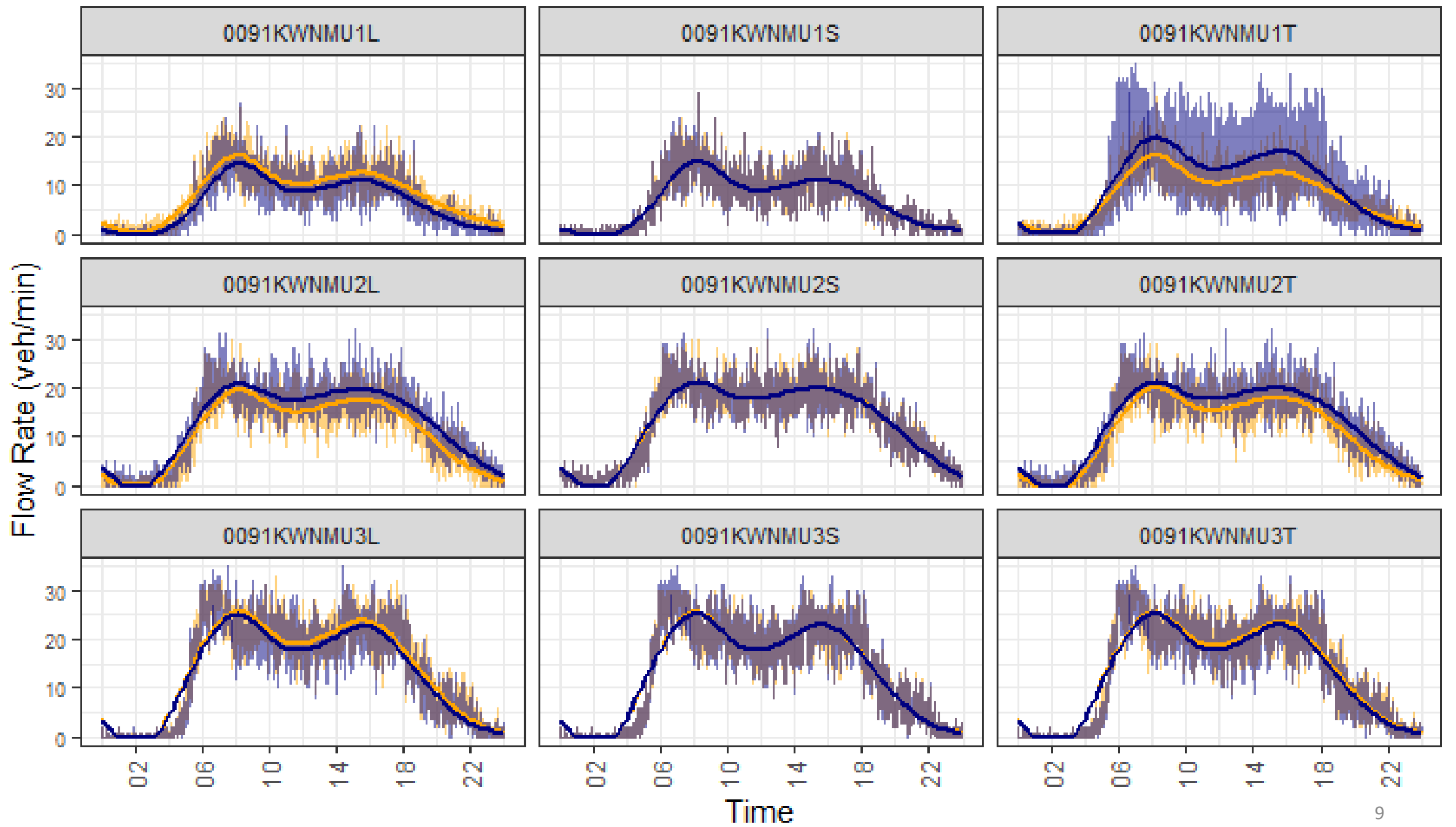
Calibration of Traffic Model

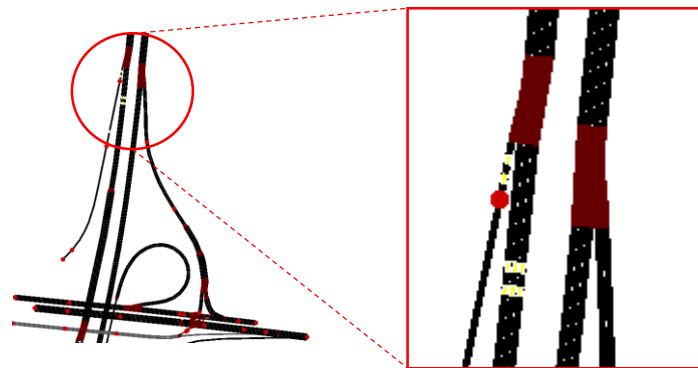
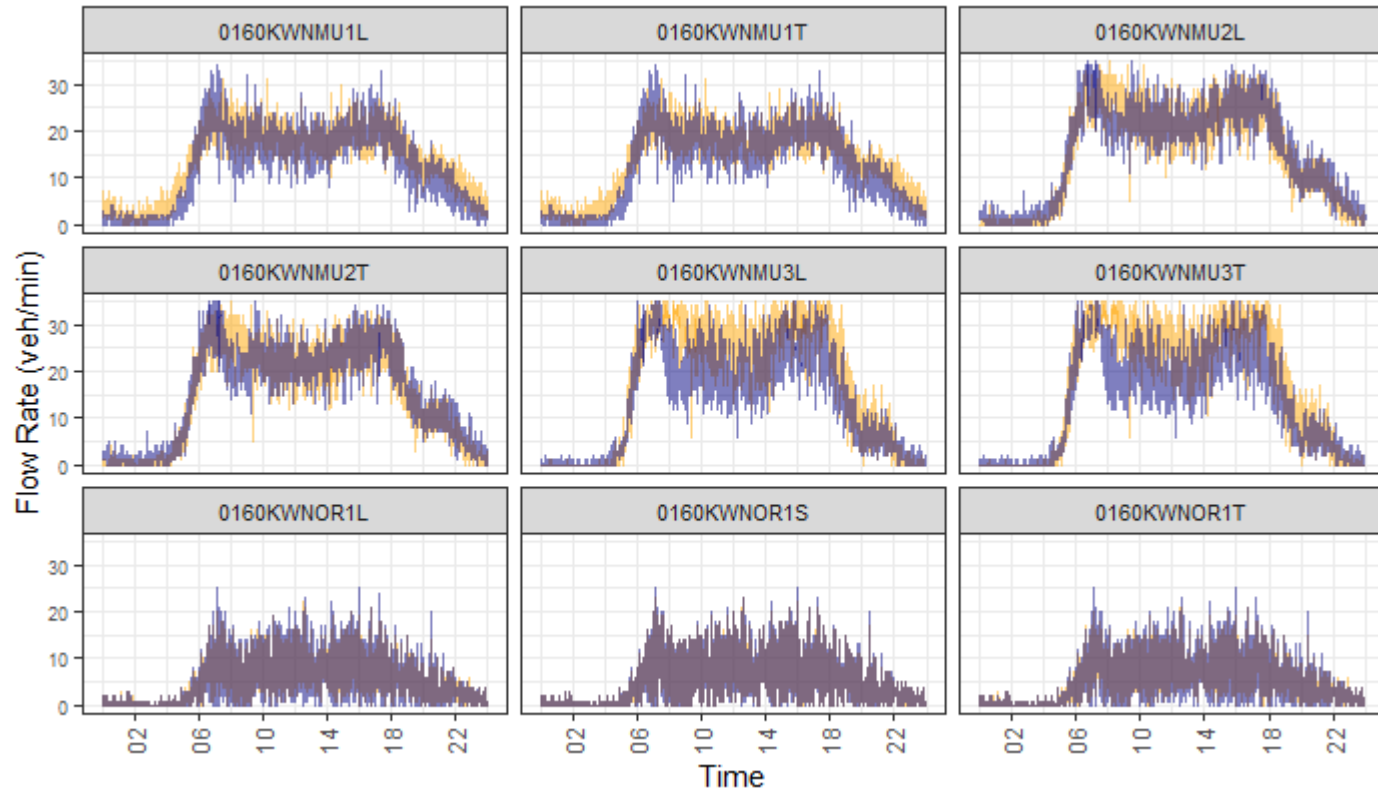
video



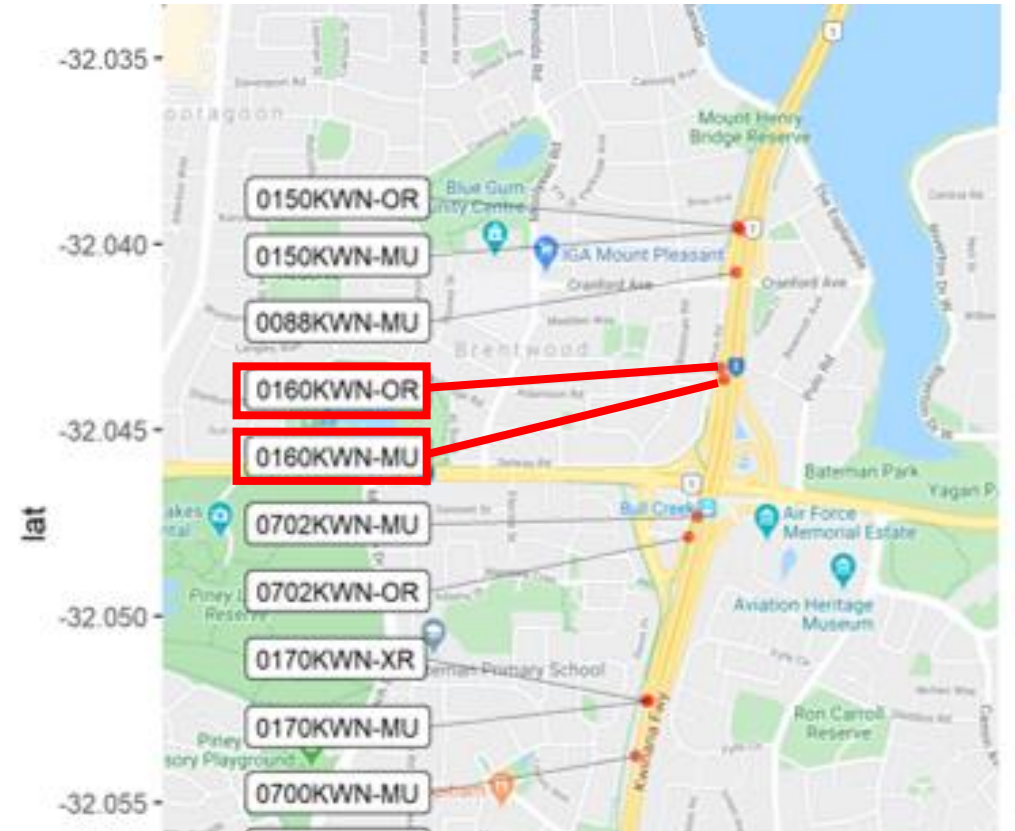
Time Series Plot of Traffic Flow on 31 Oct 2018

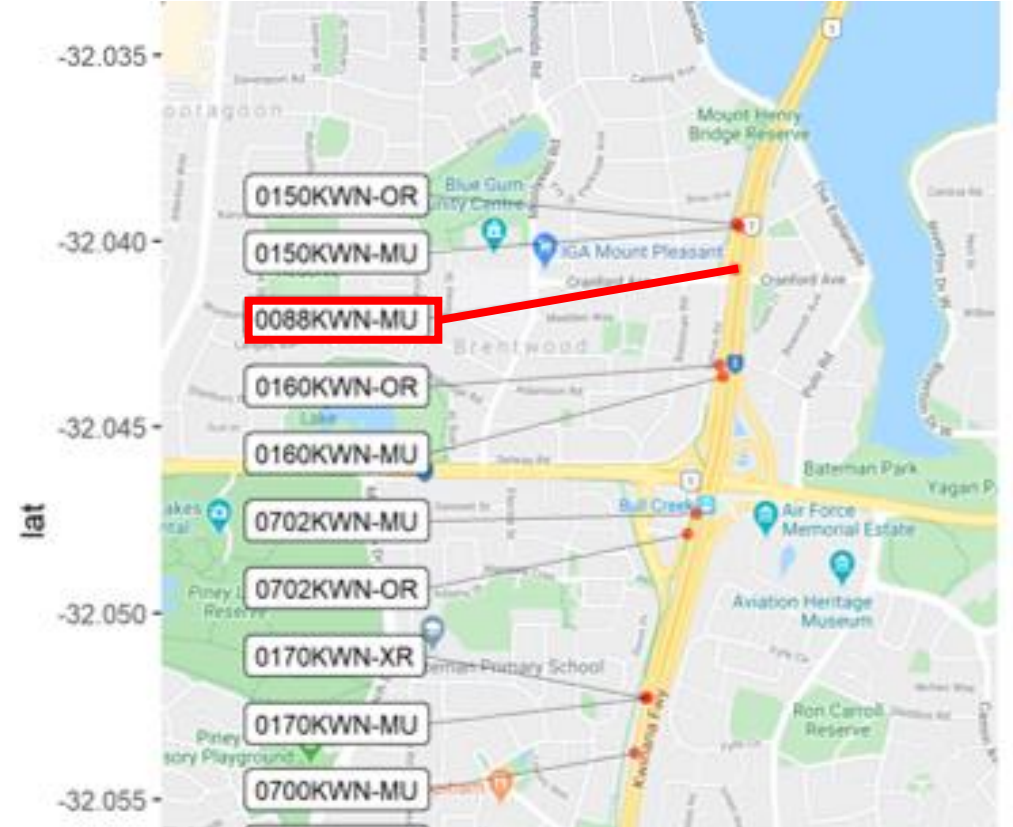
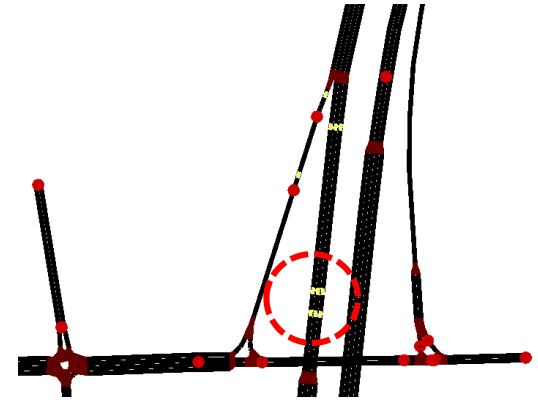
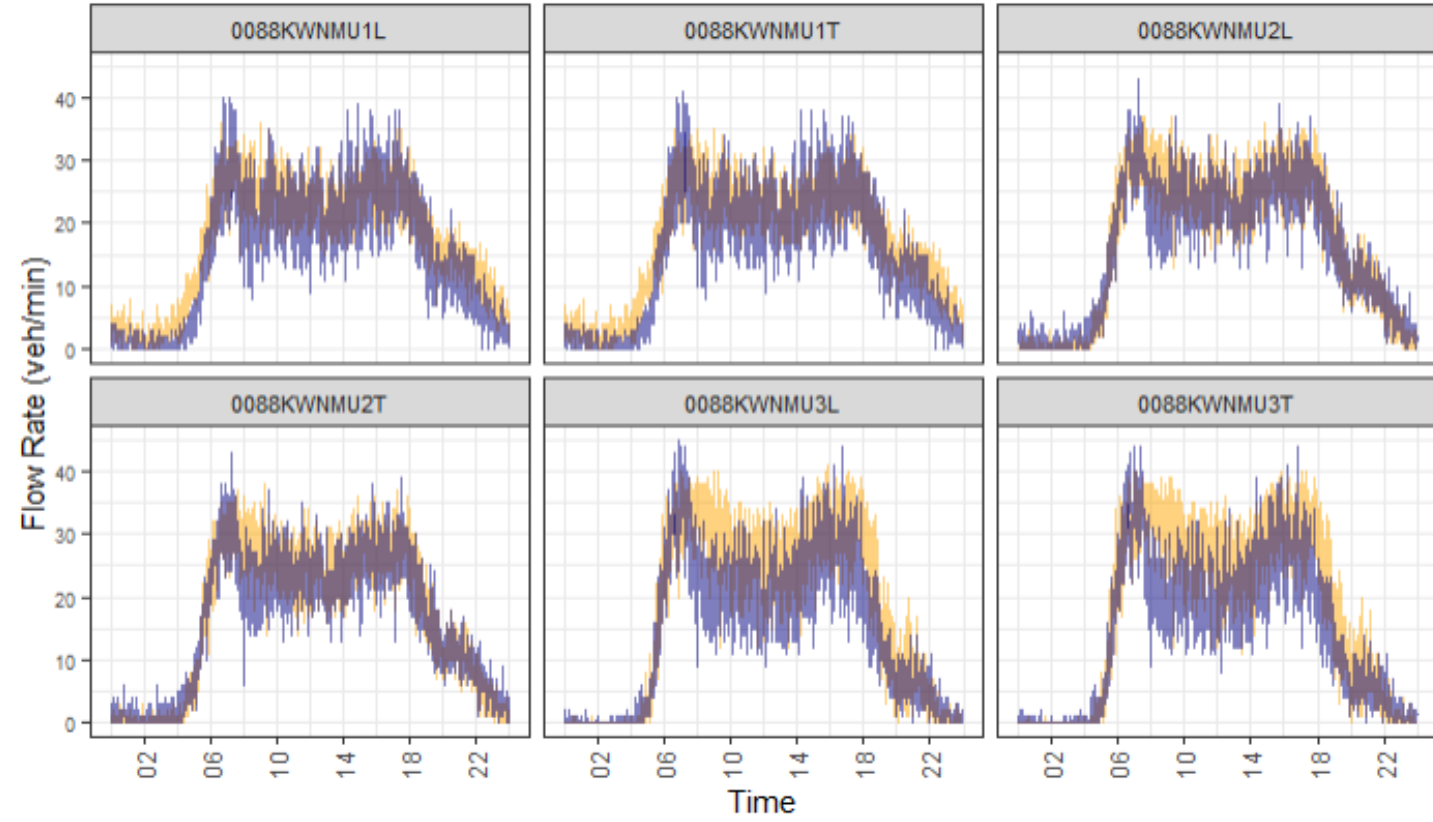


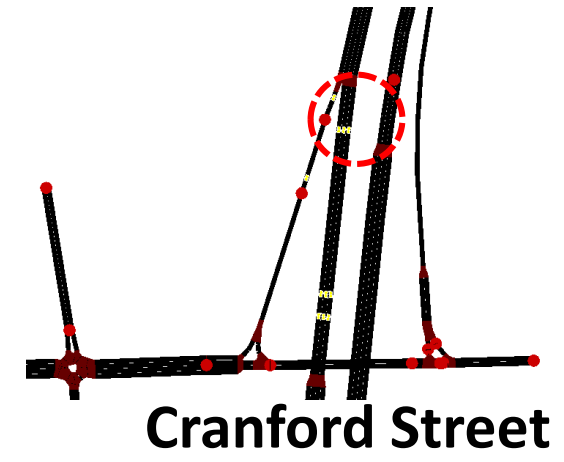
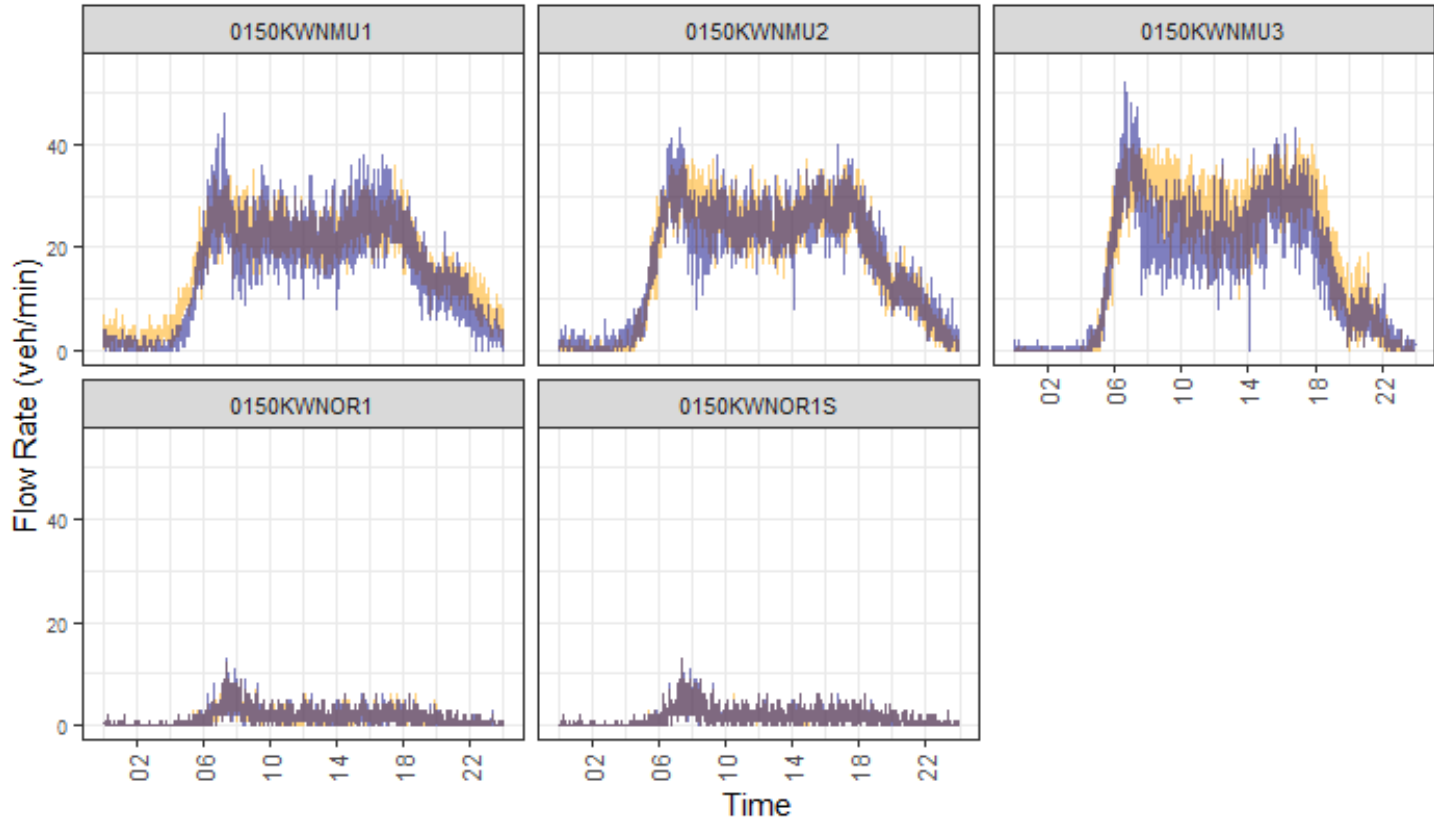


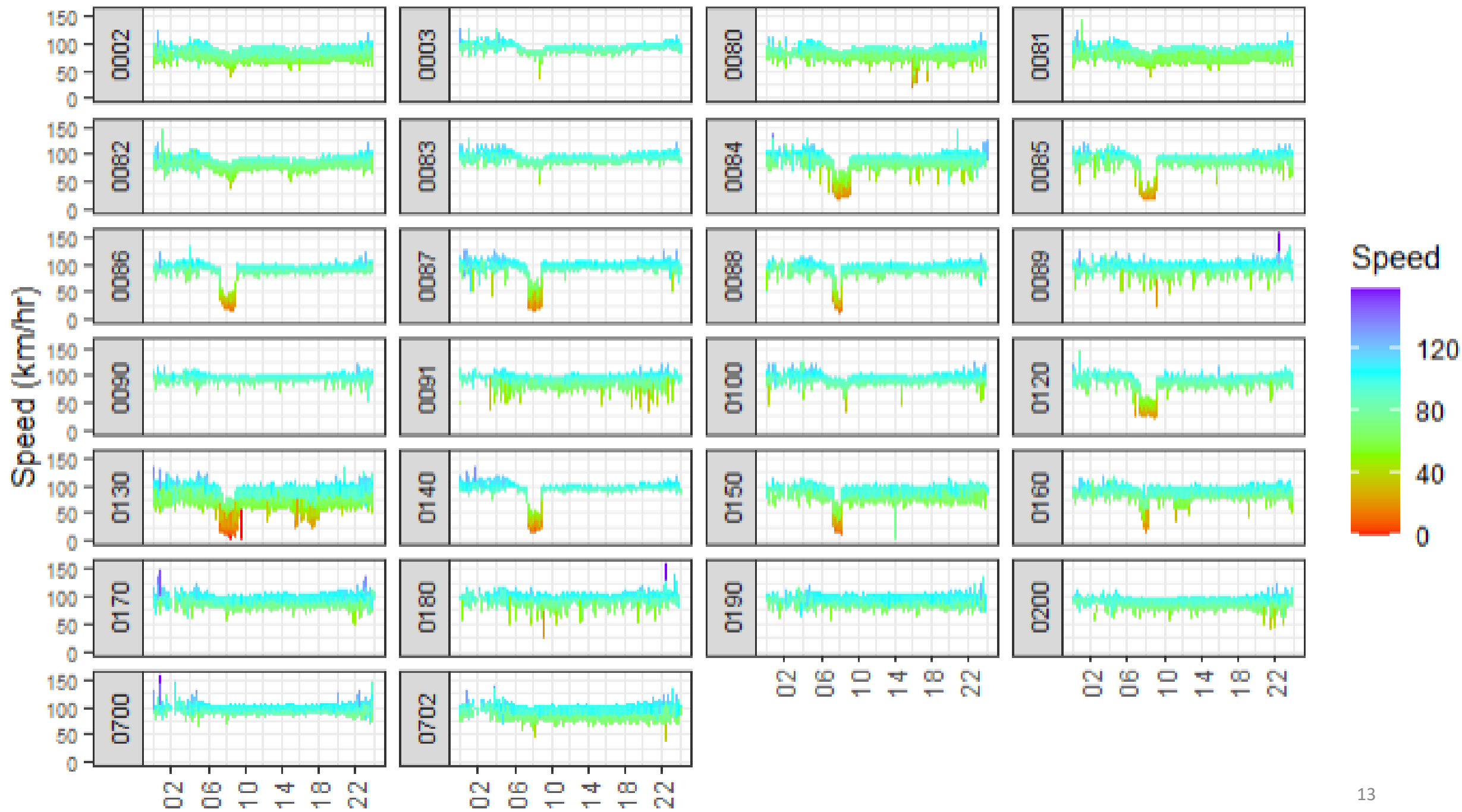


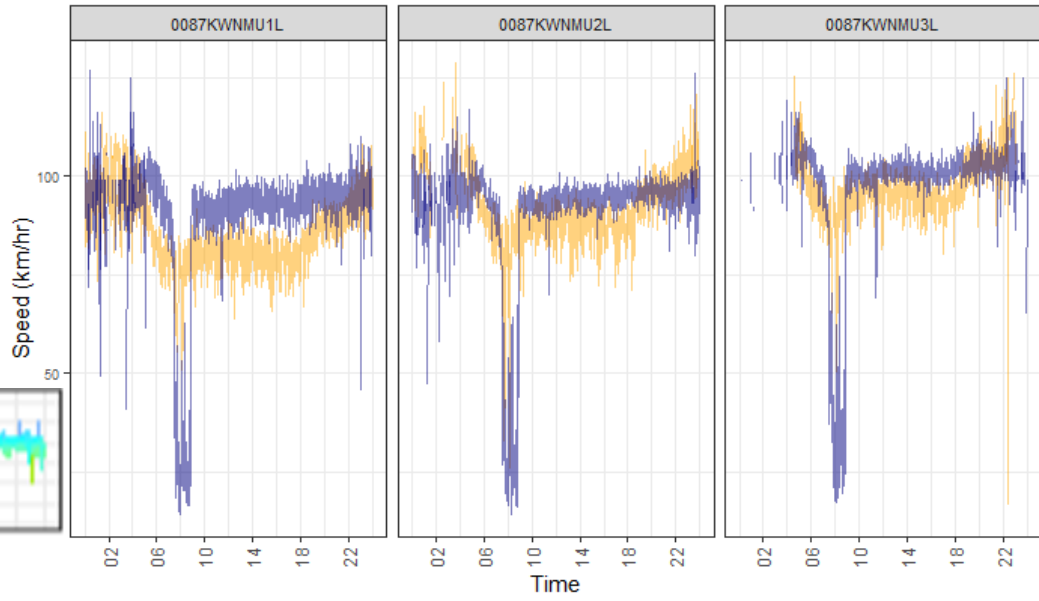
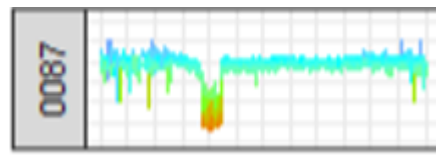
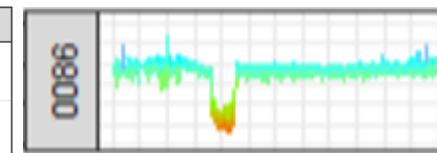
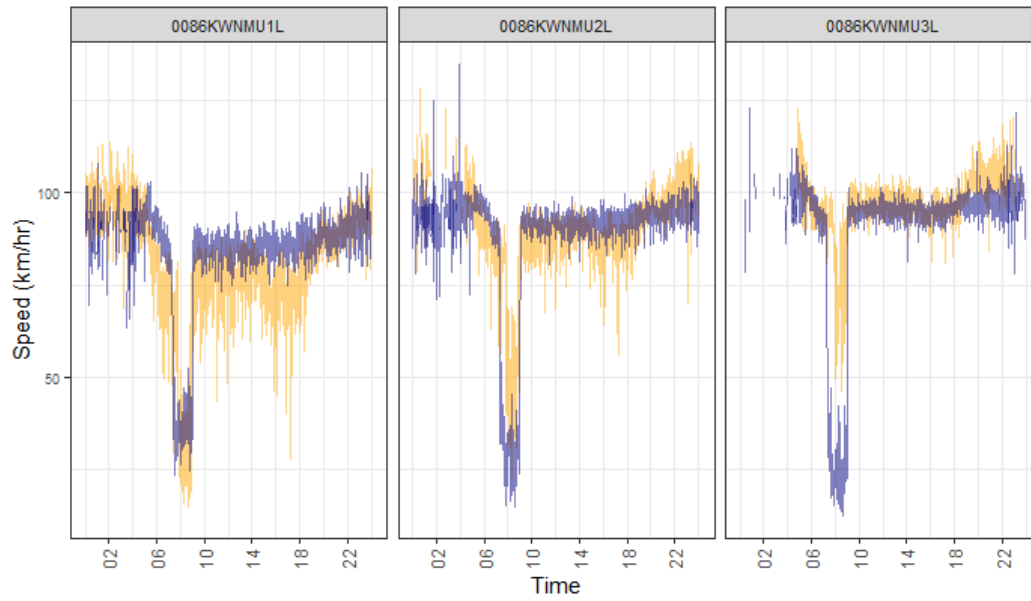
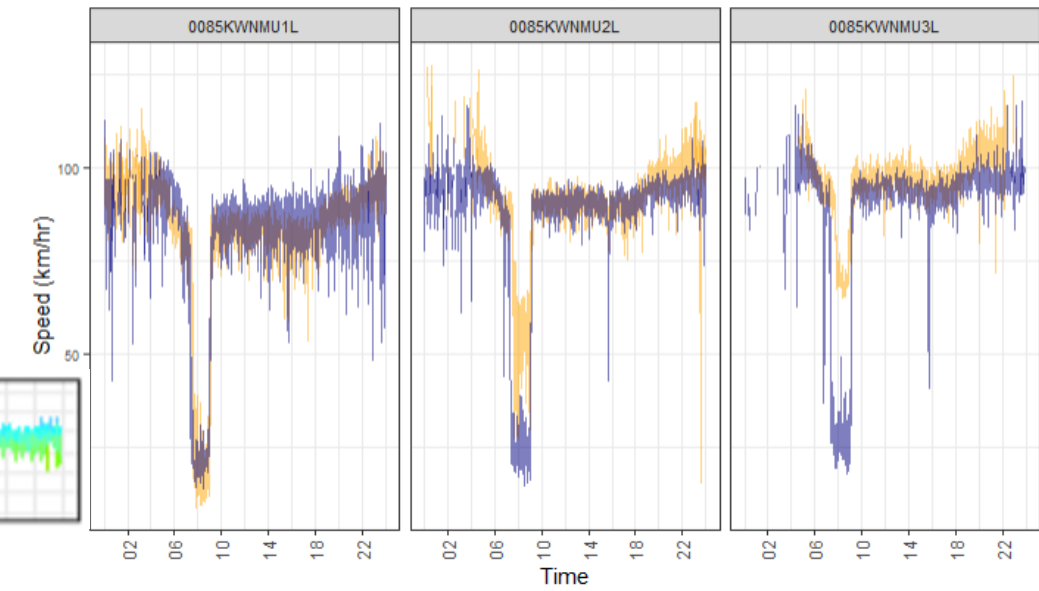
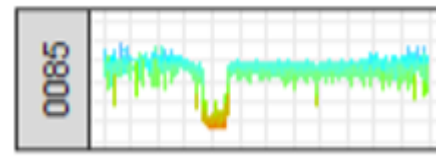
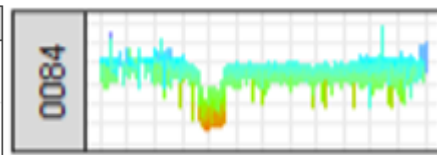
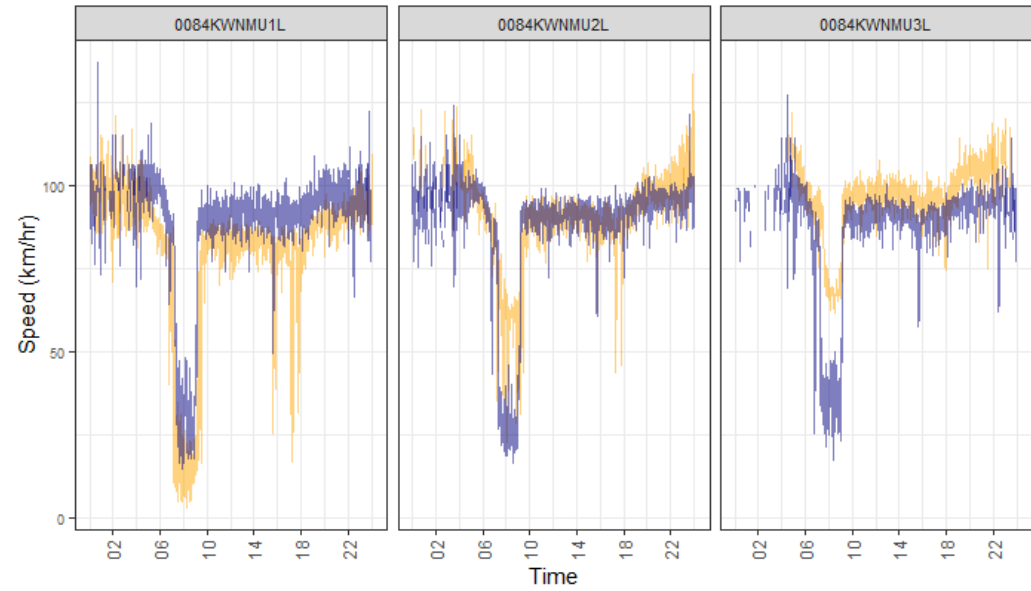
Leach Hwy

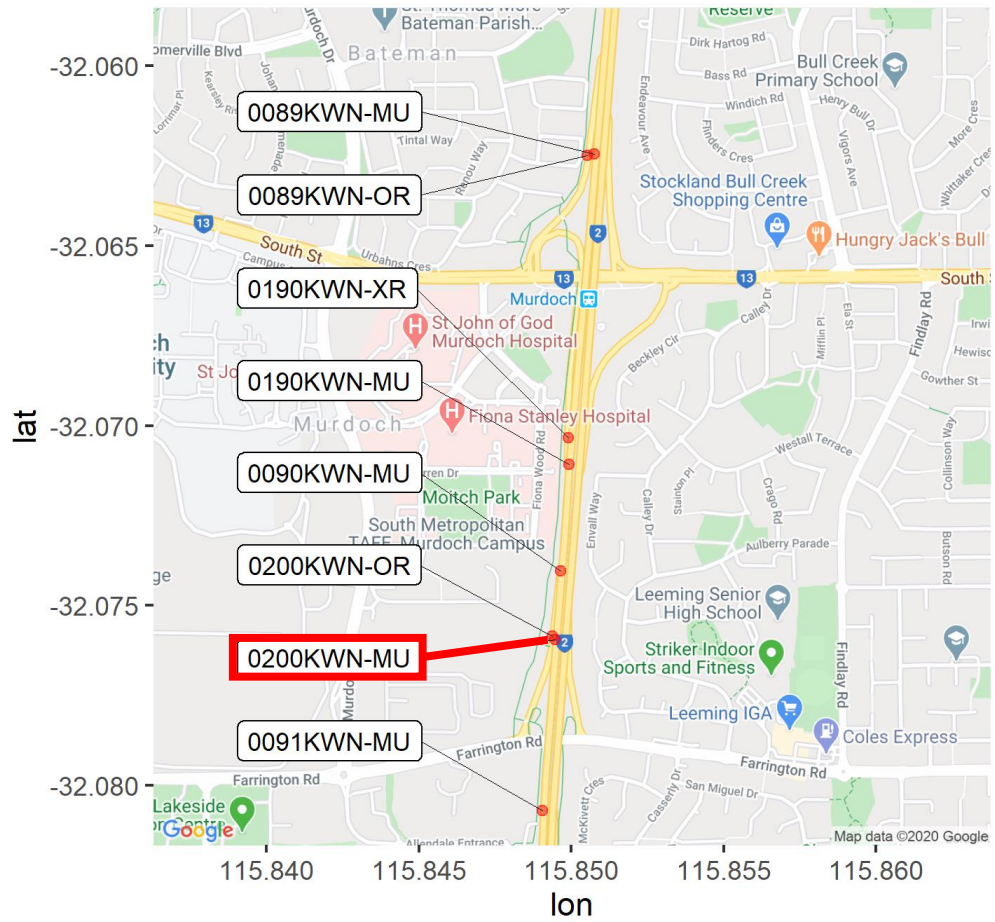
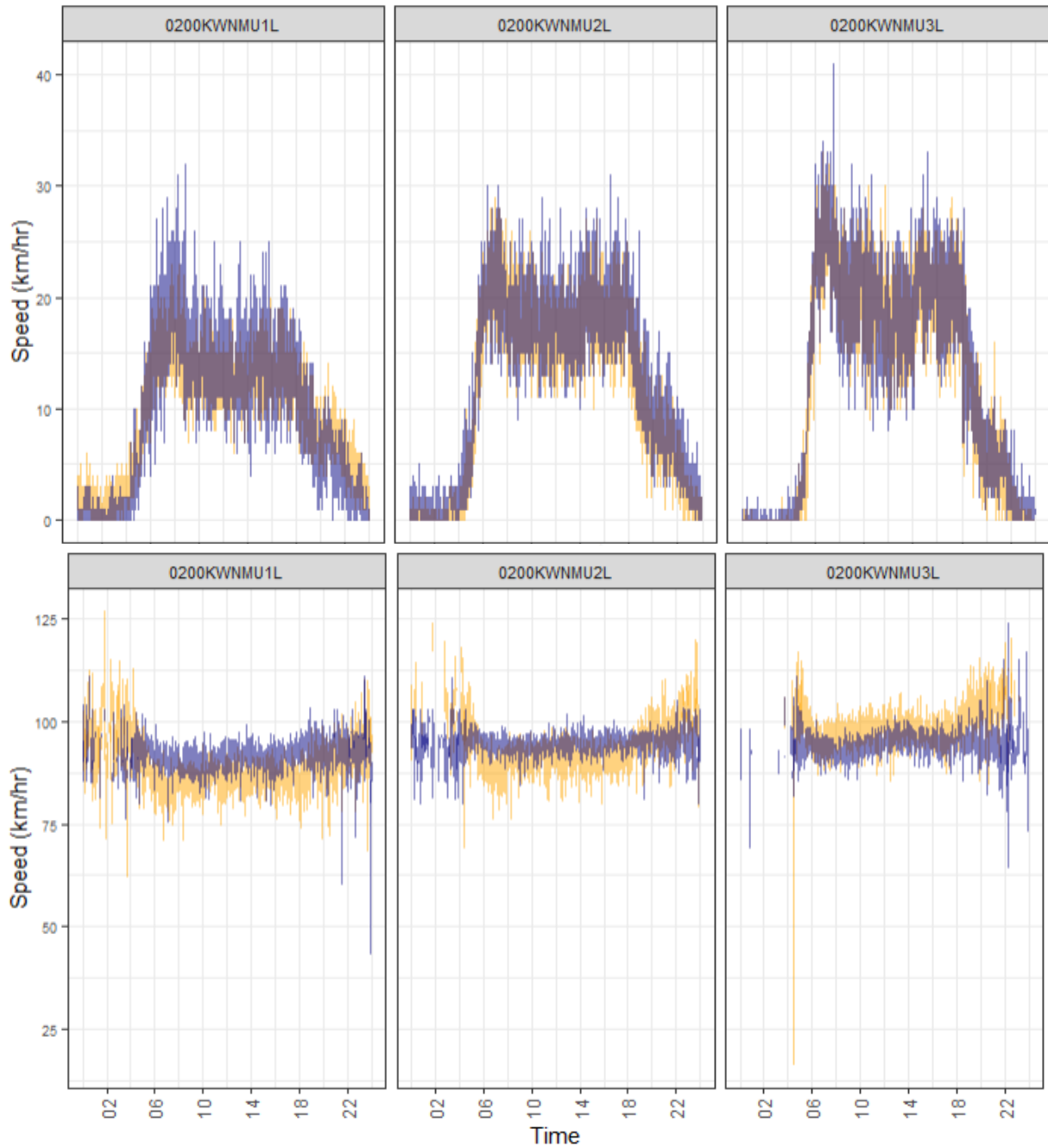




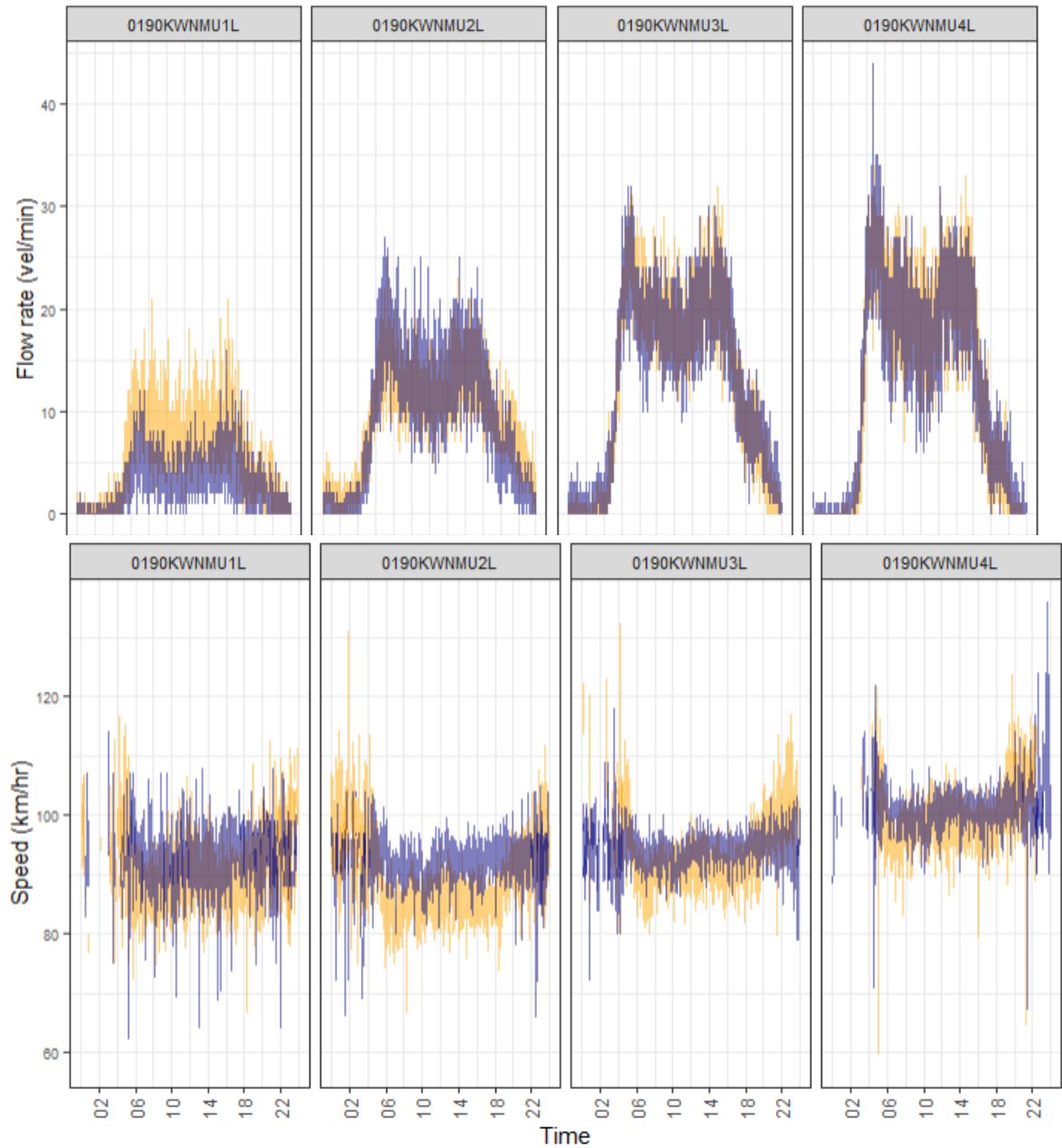
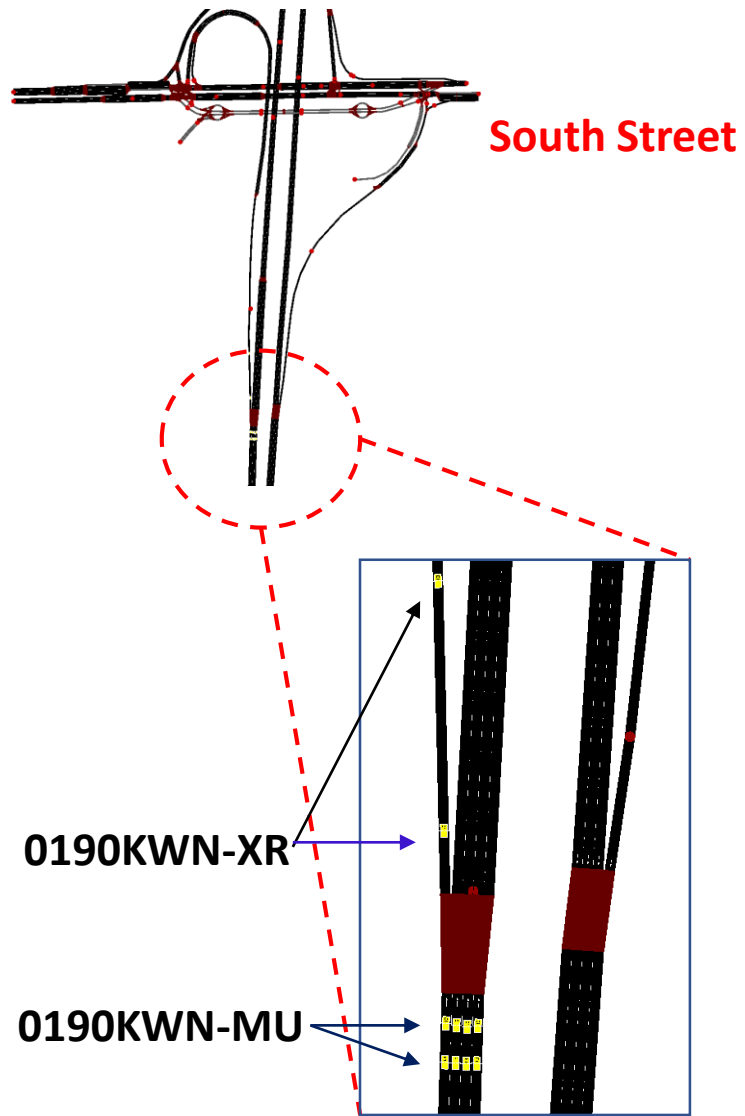


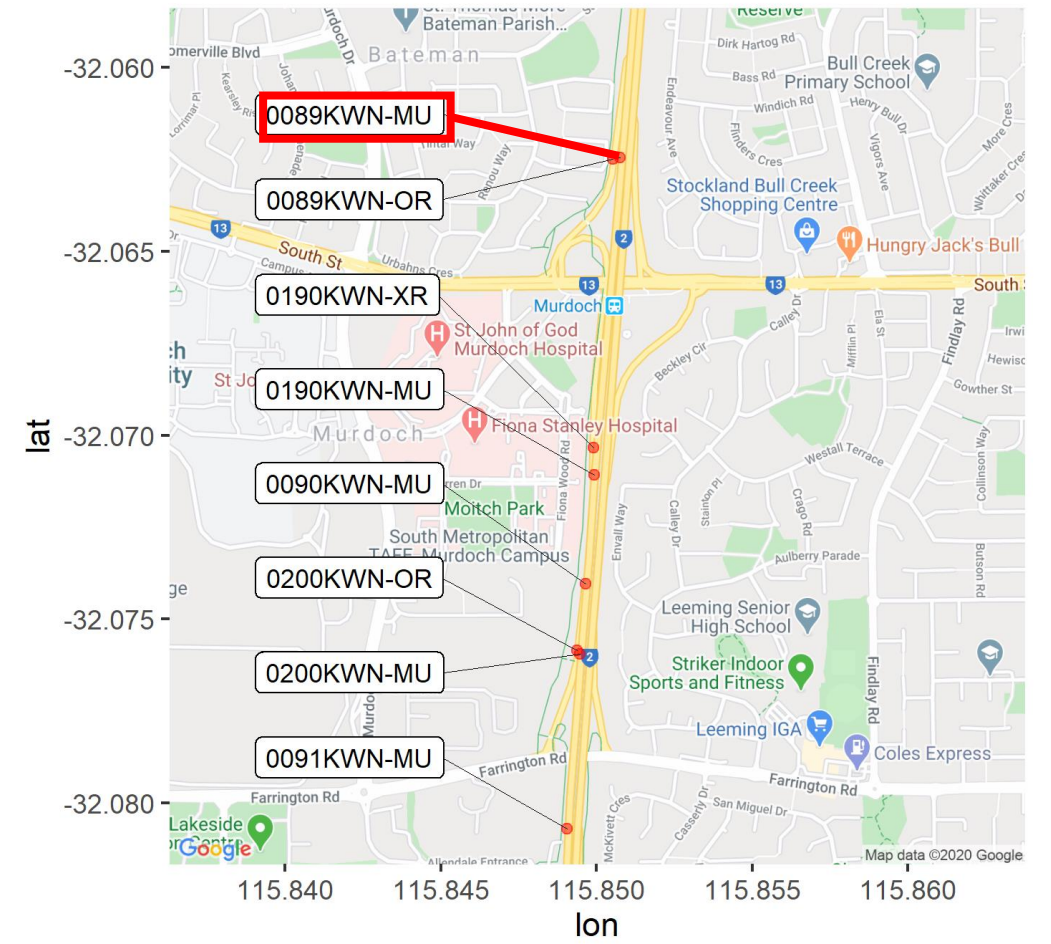
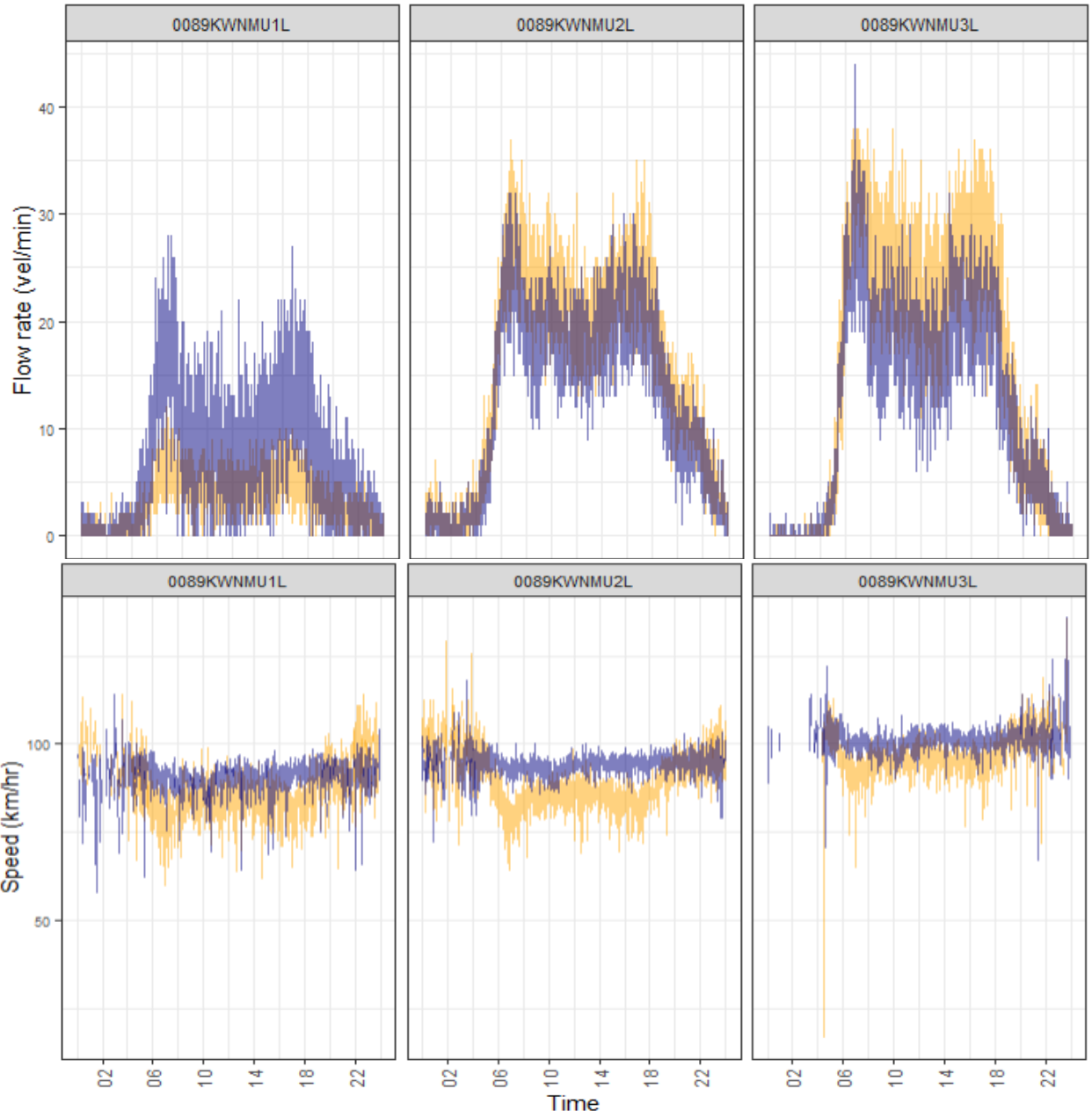




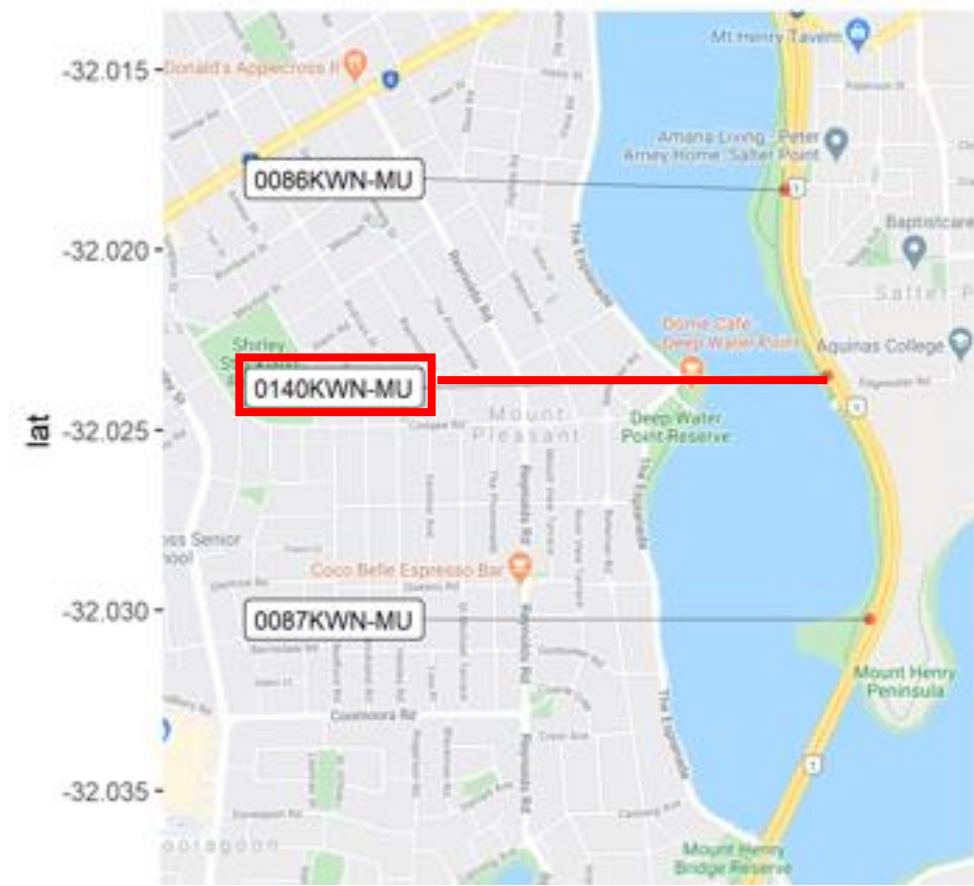
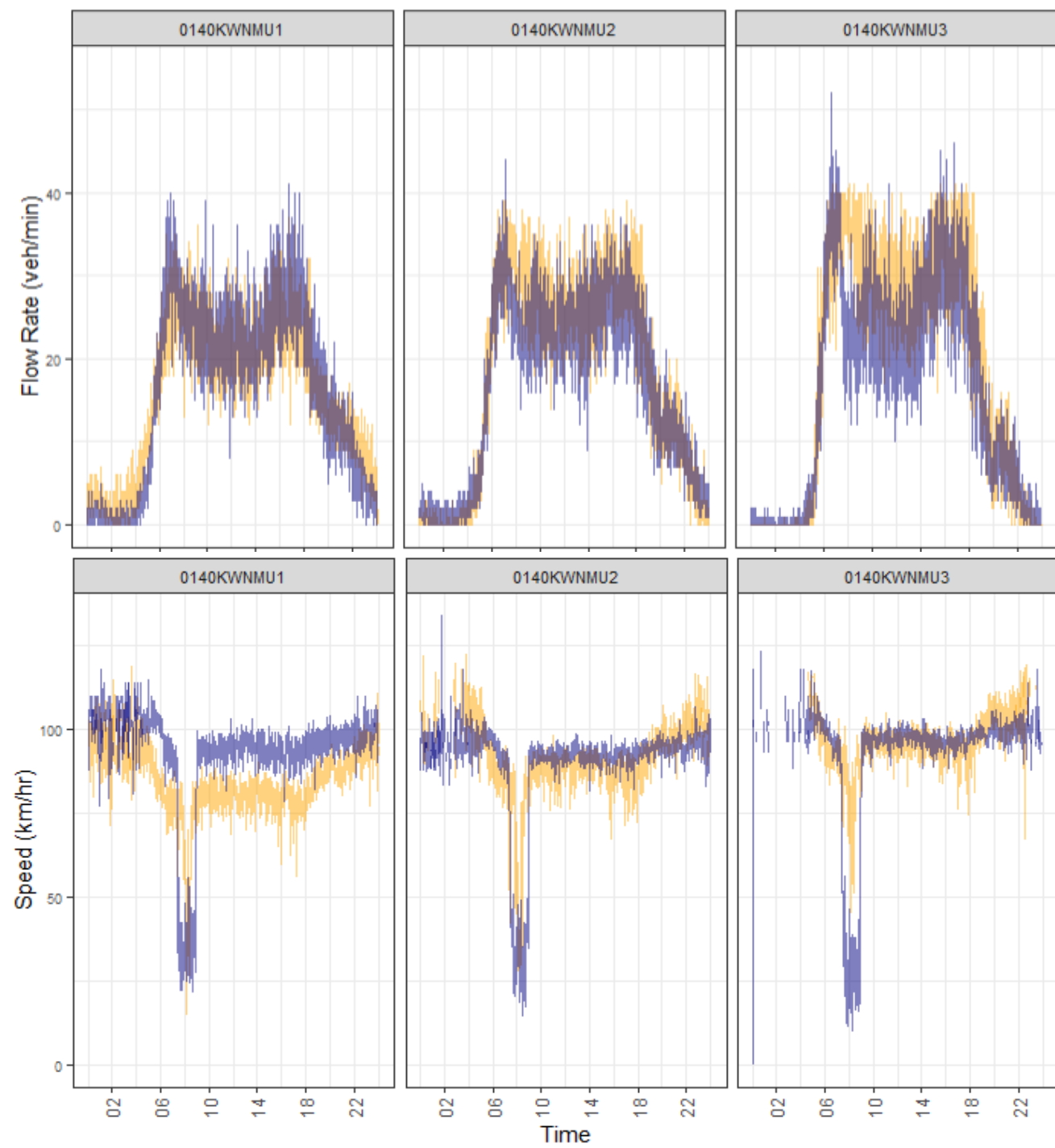


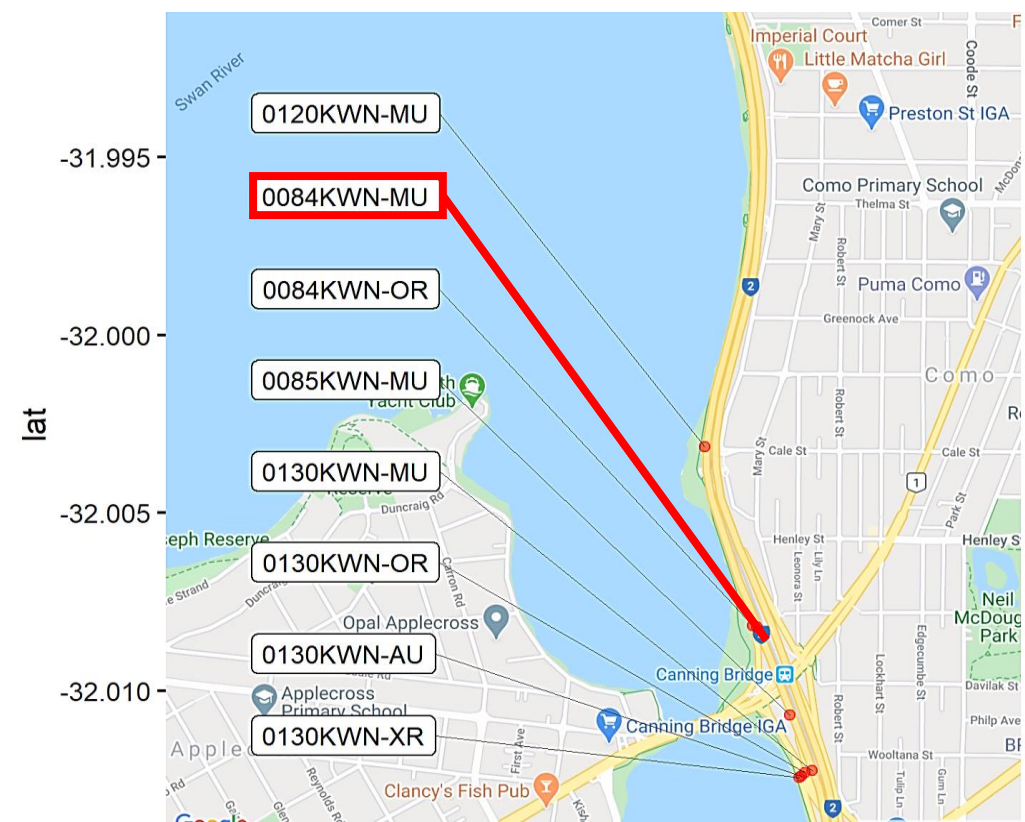
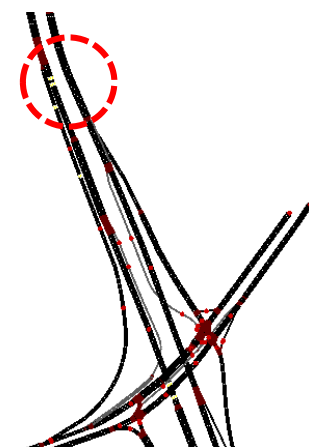
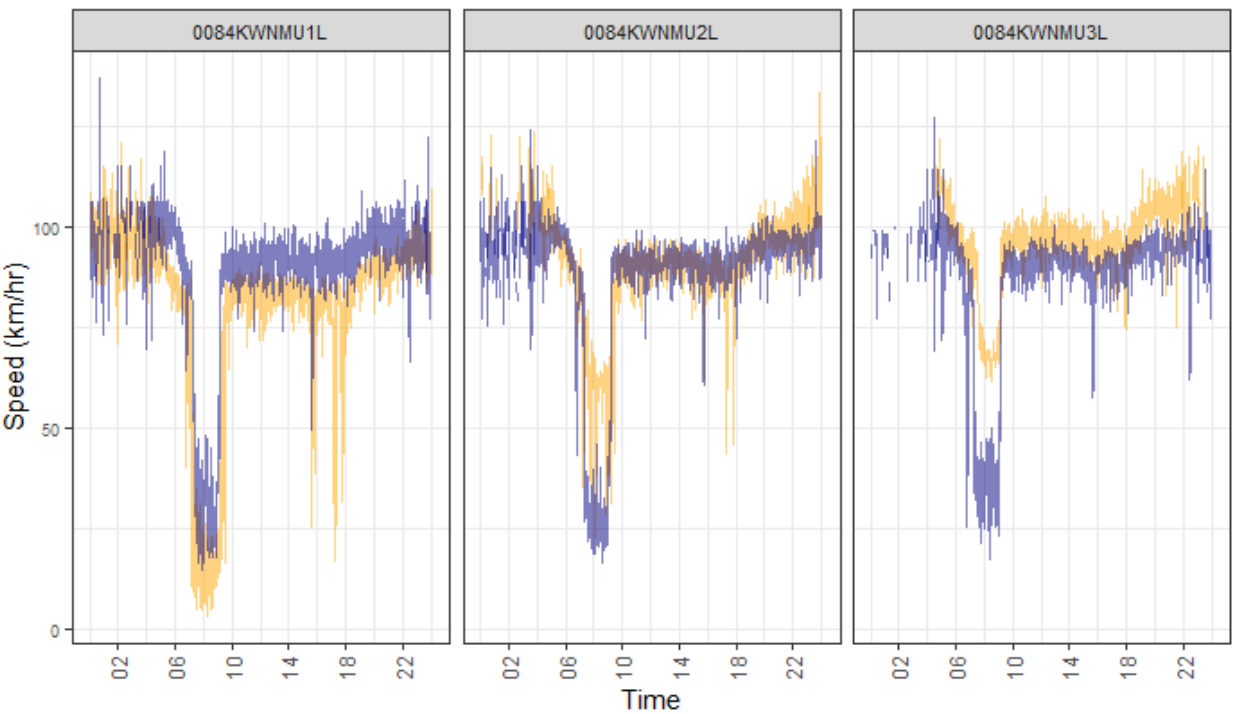
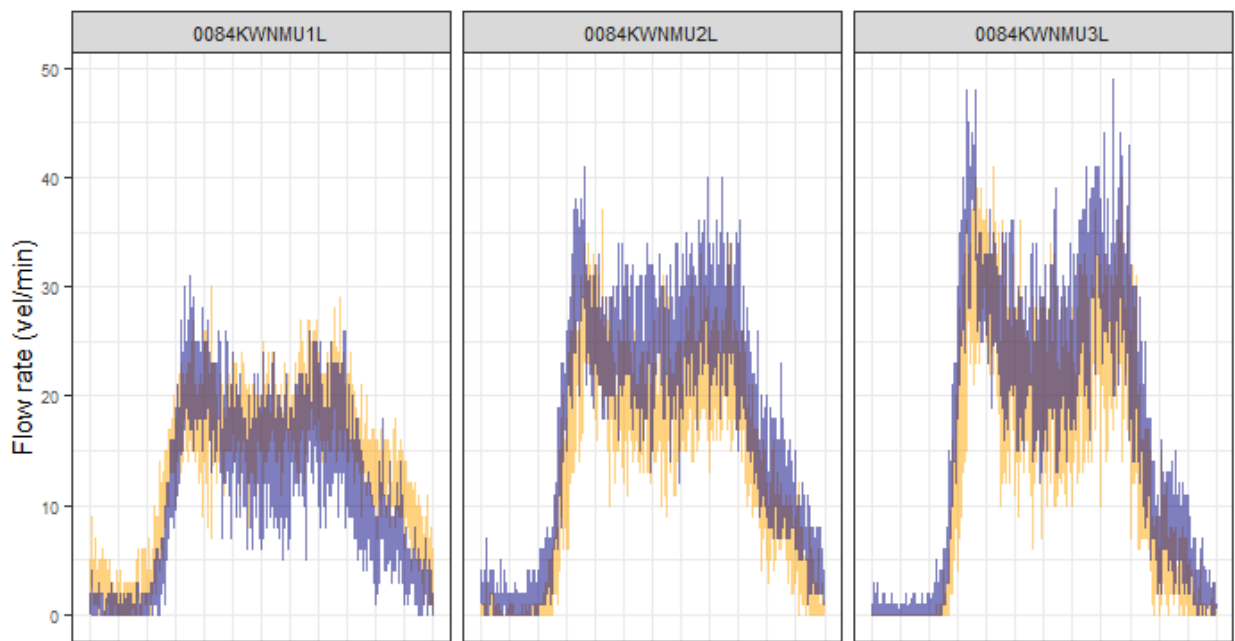
Farrington Street

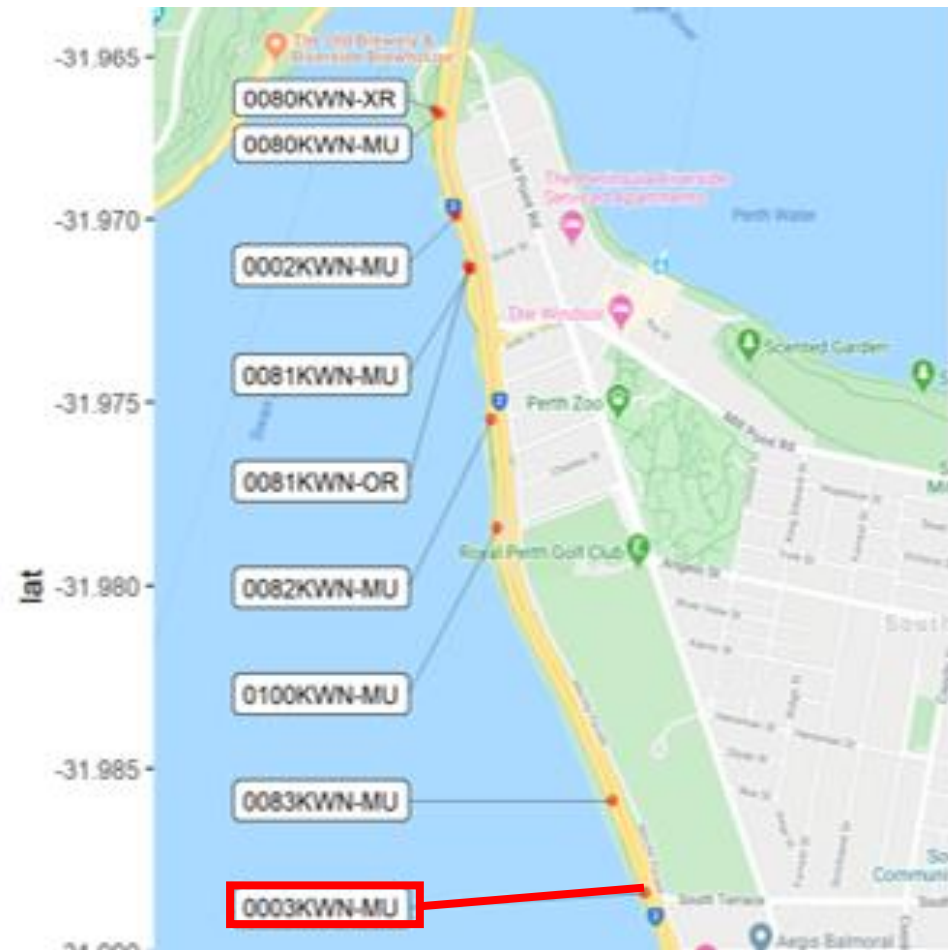
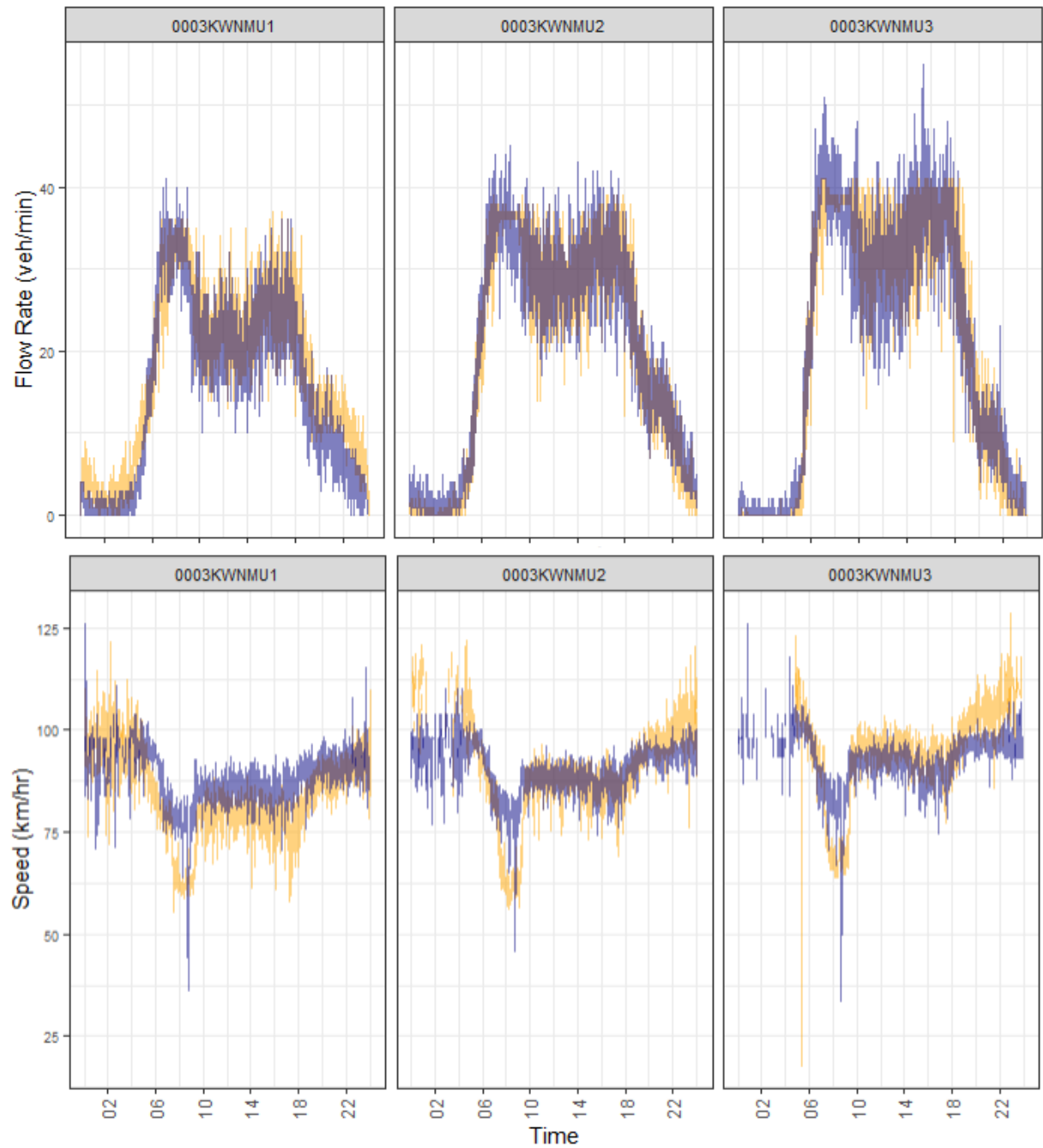


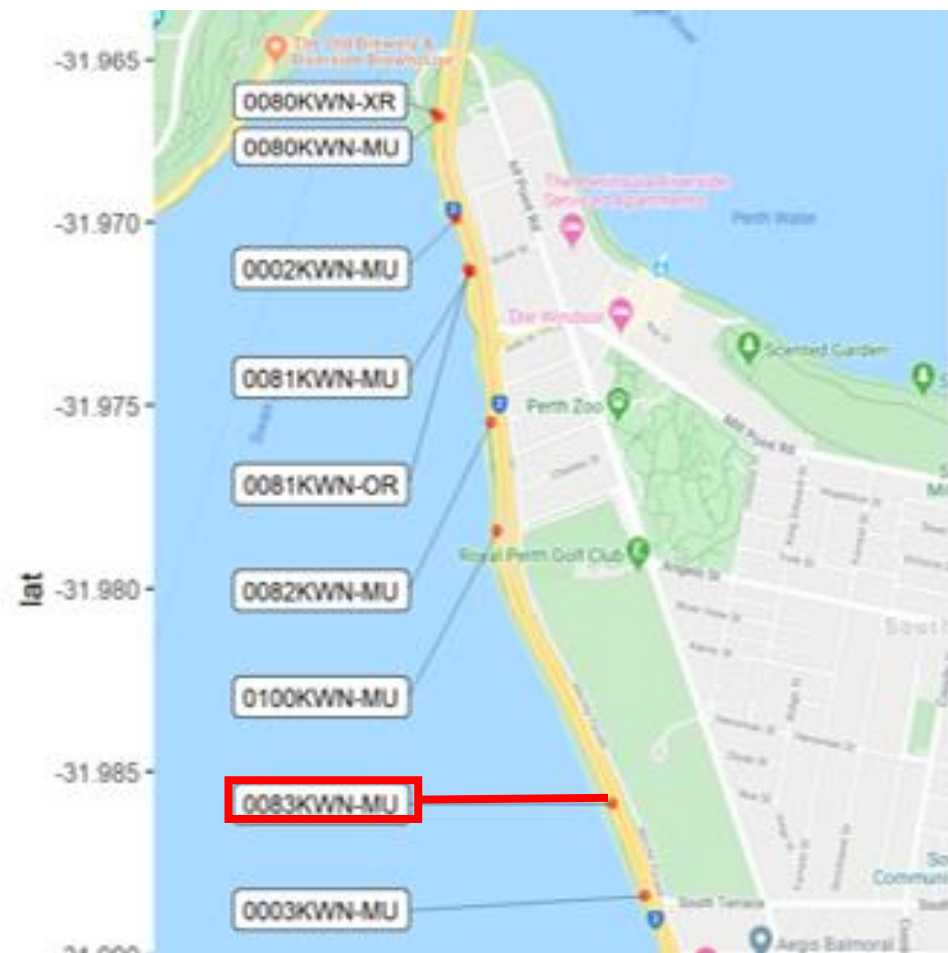
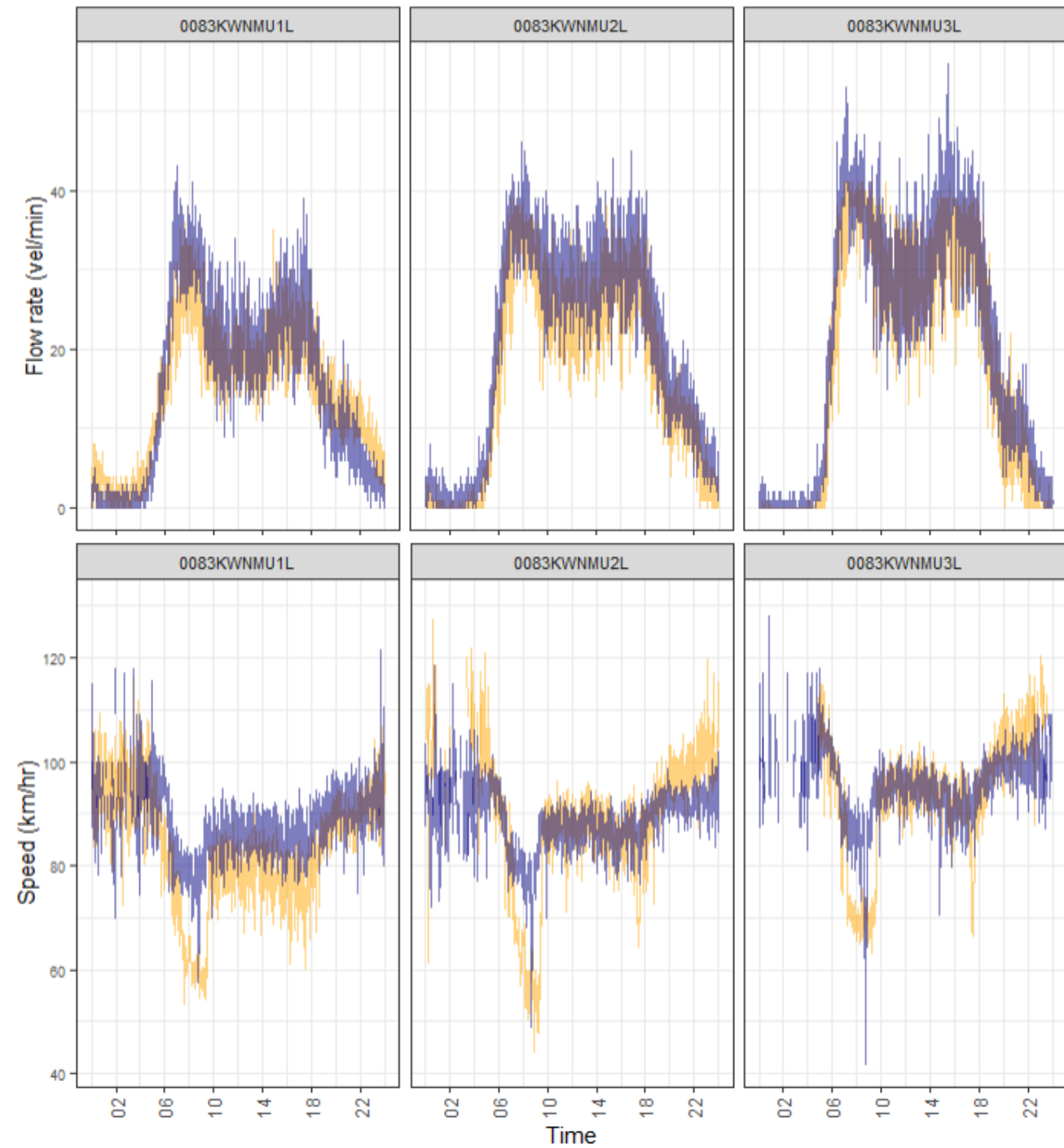


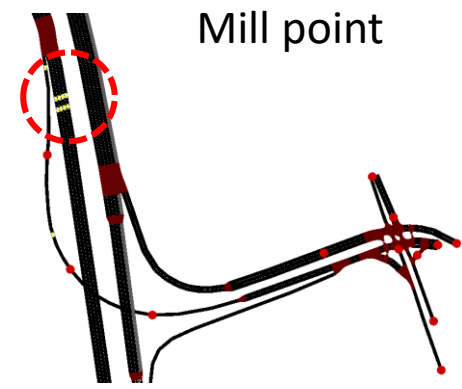
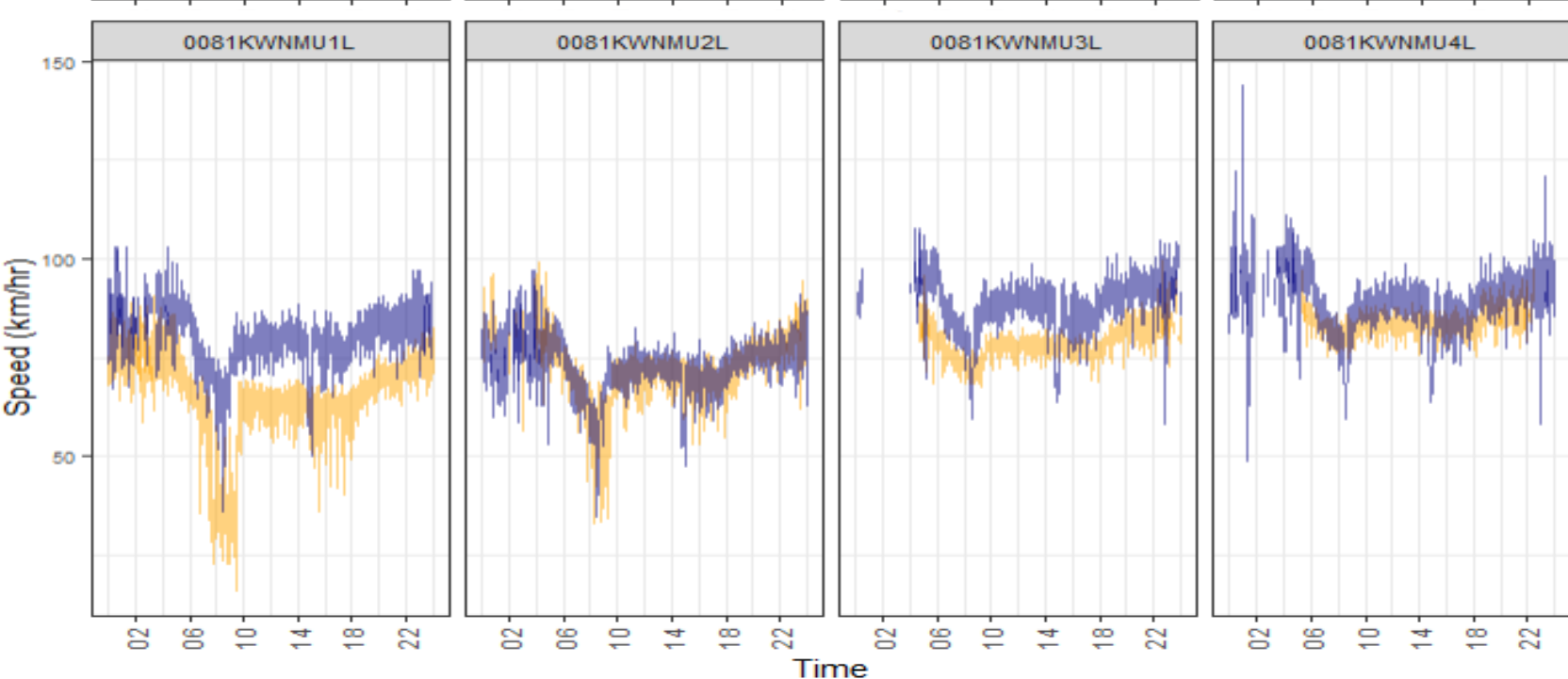
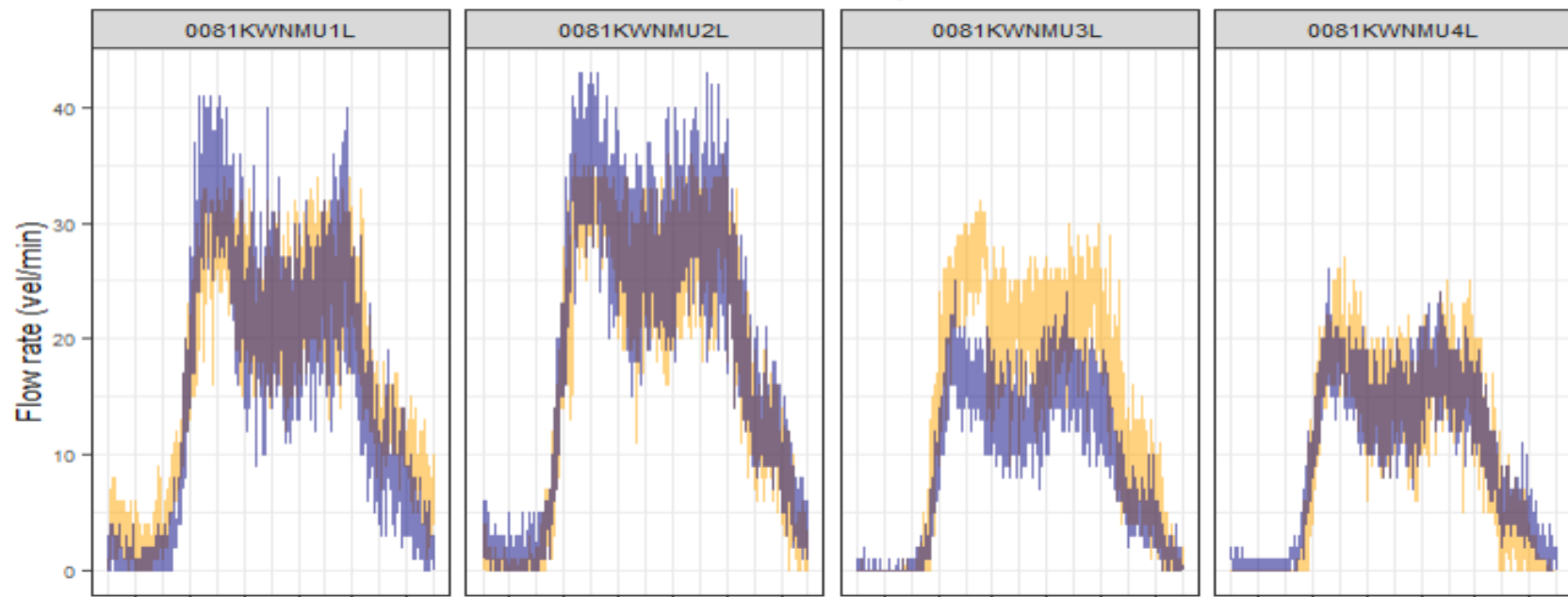
South Street



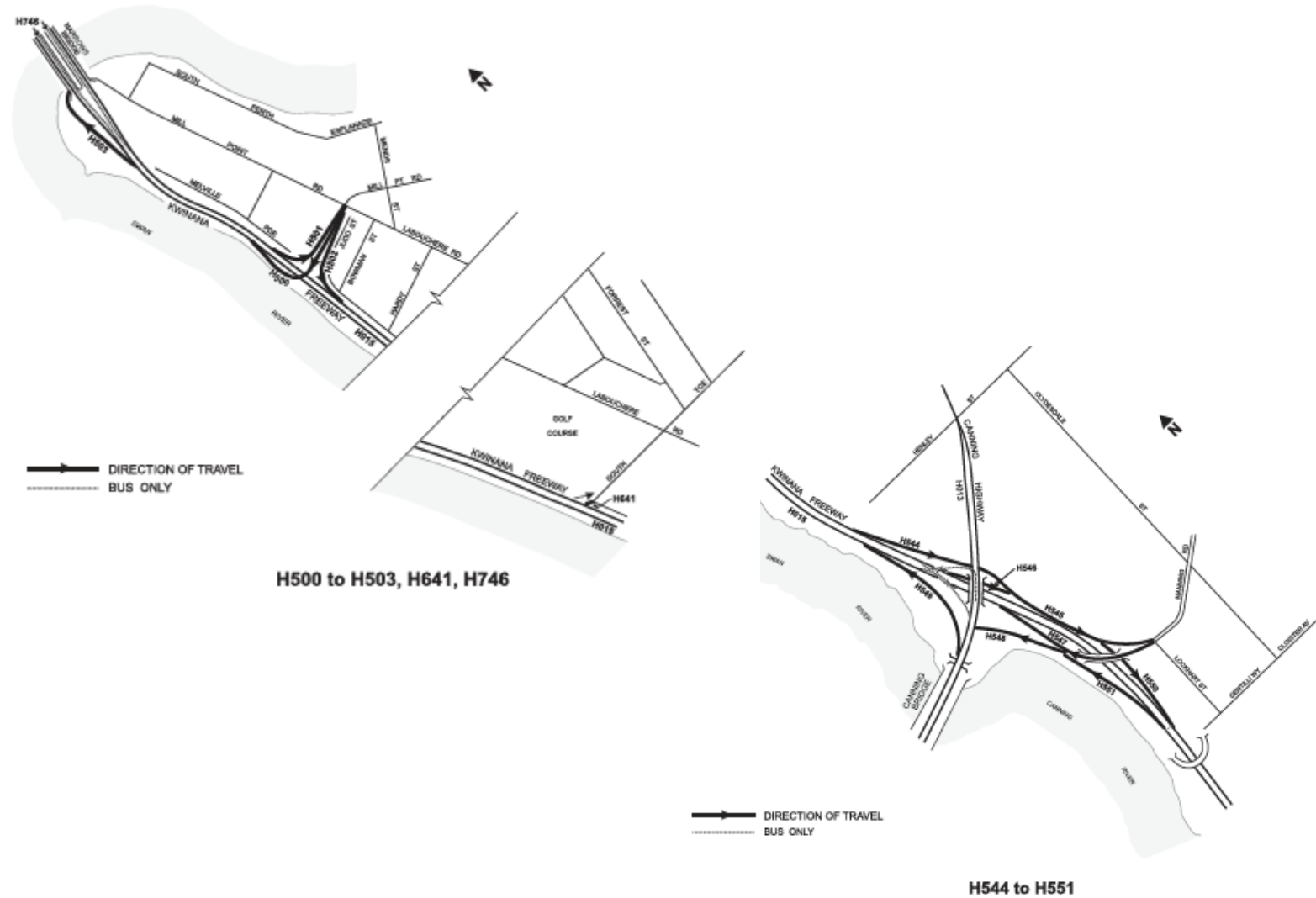








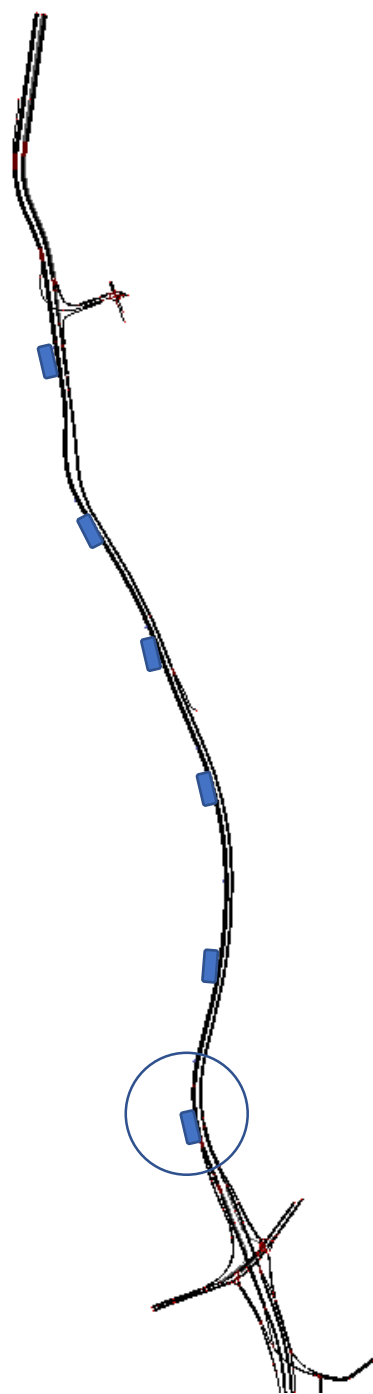
2 Implementation of the new KWN Freeway configuration



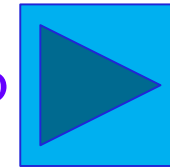
From Canning Highway to Narrow Bridge: NPI link 10 to 13



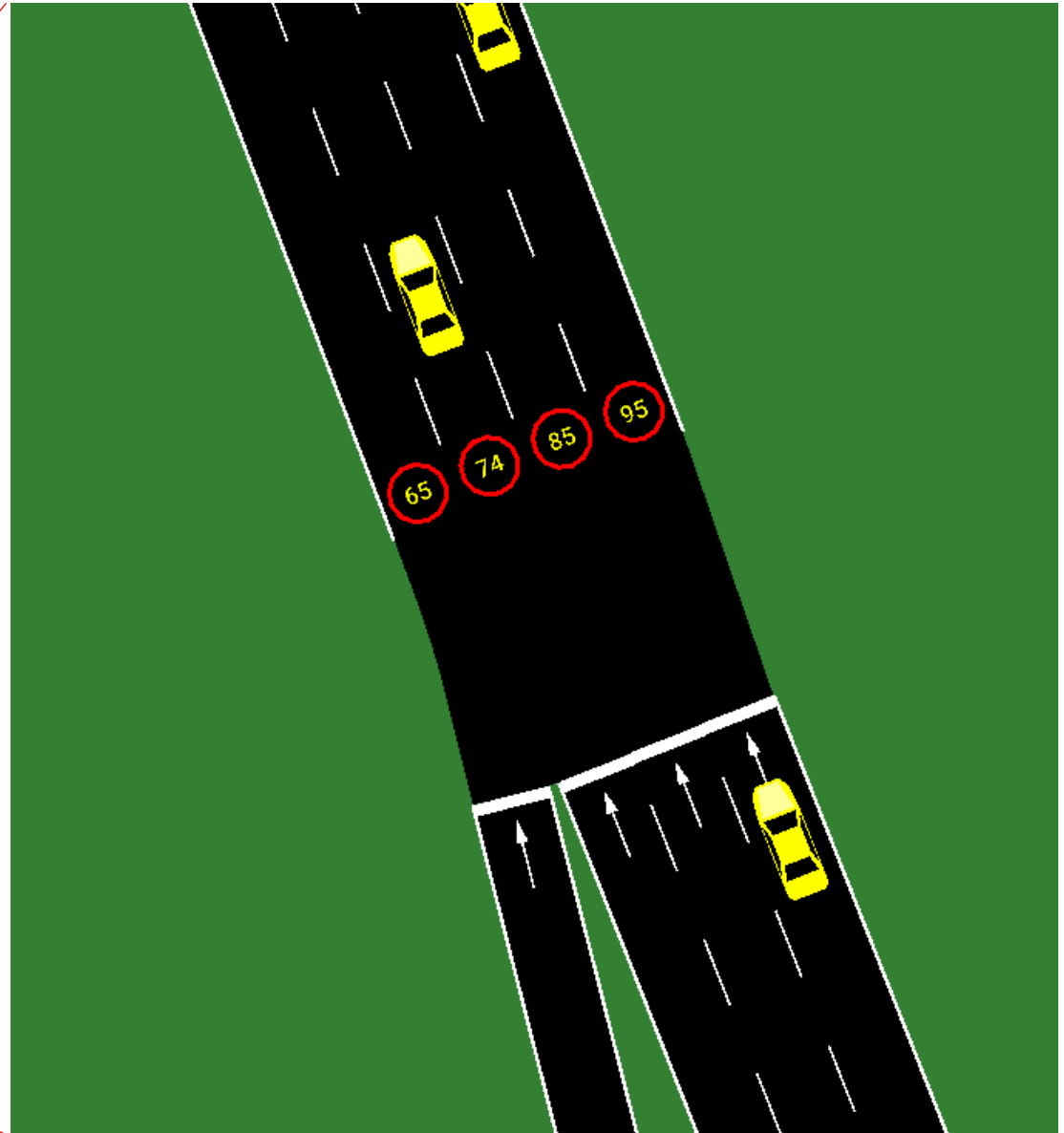
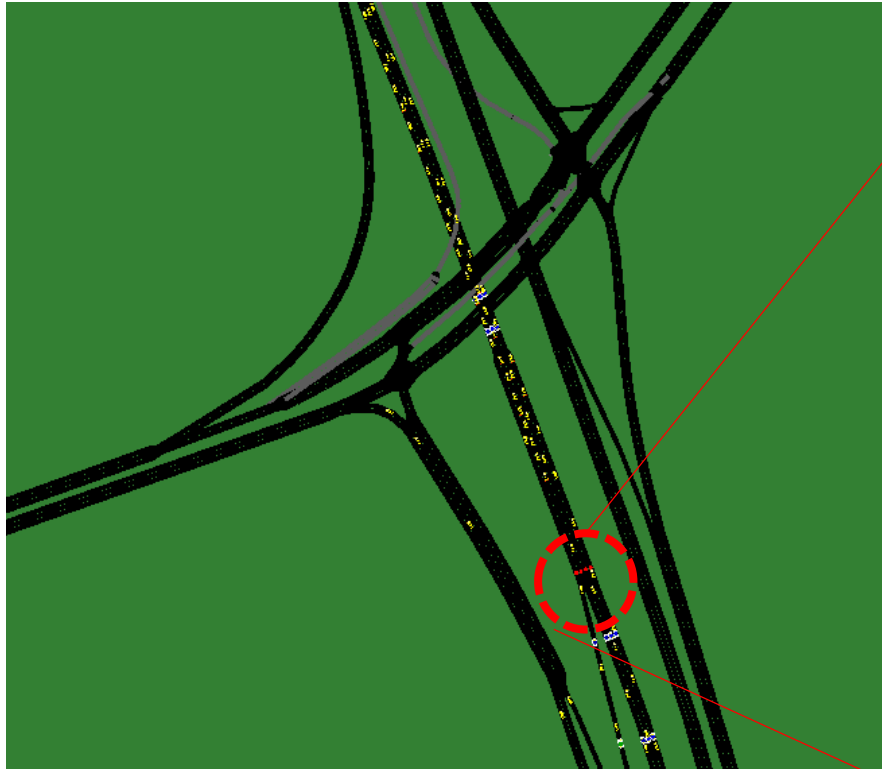
1 additional lane
6 parking areas

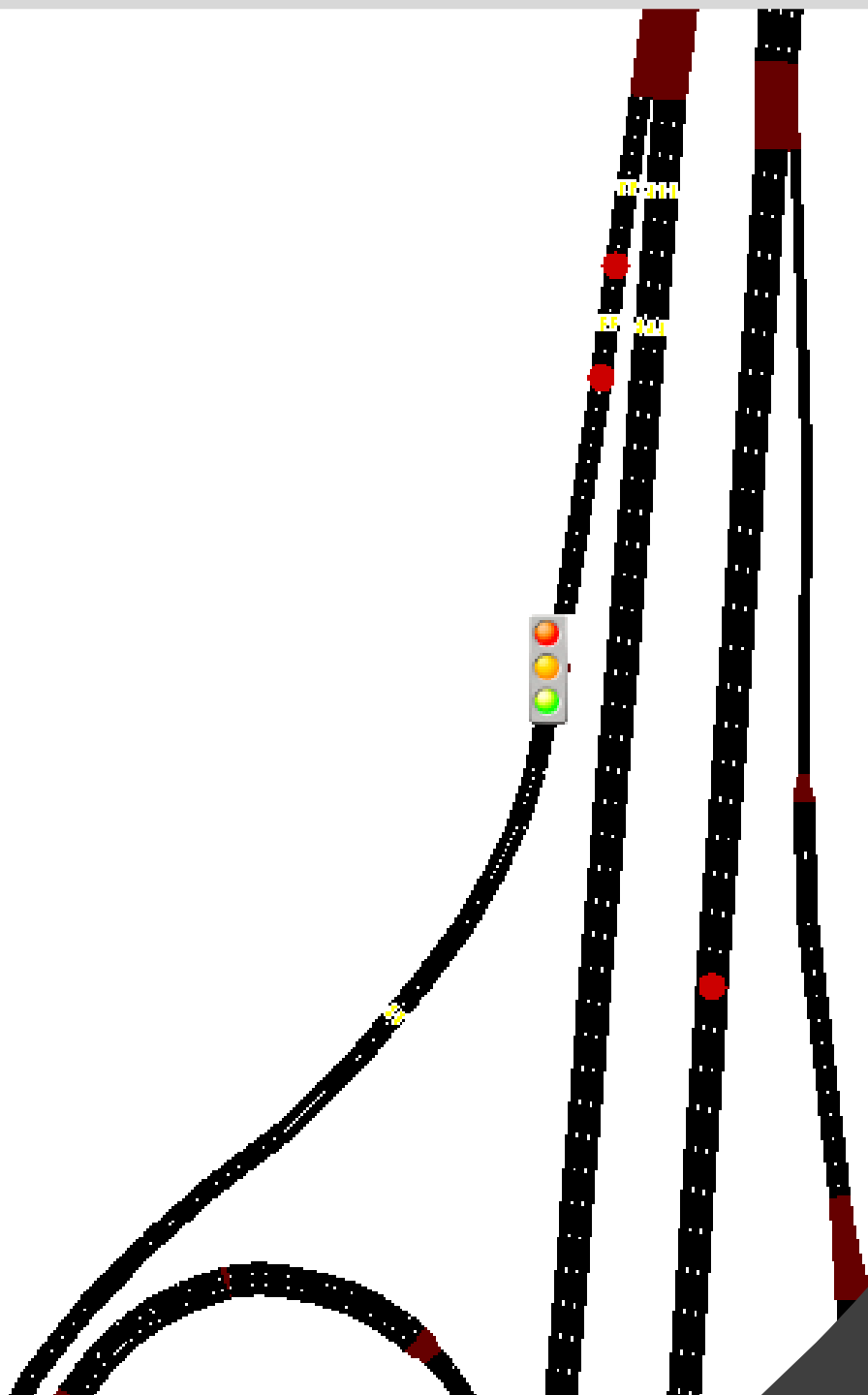


video



Simulation examples on new configuration with RM and VSL



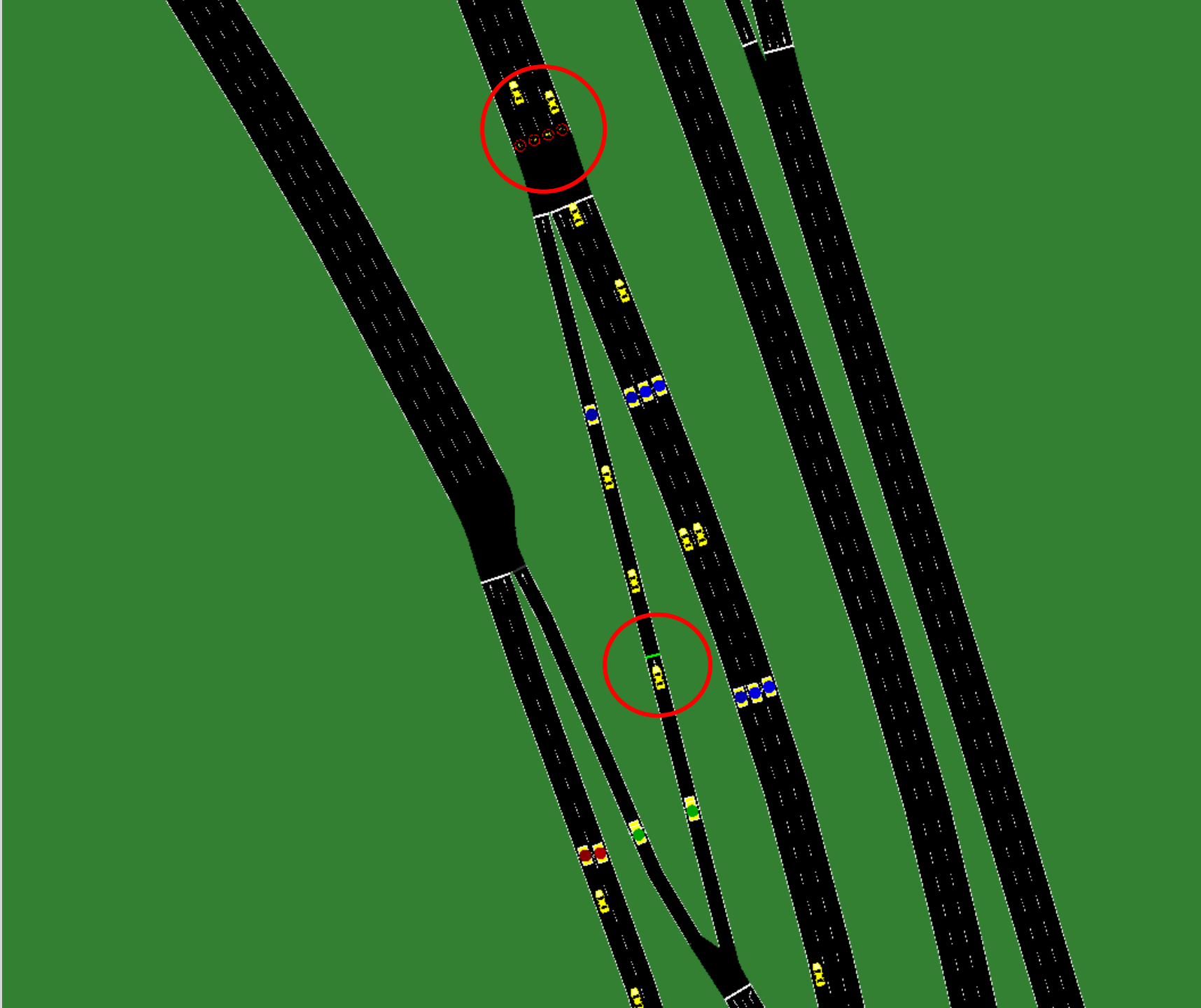


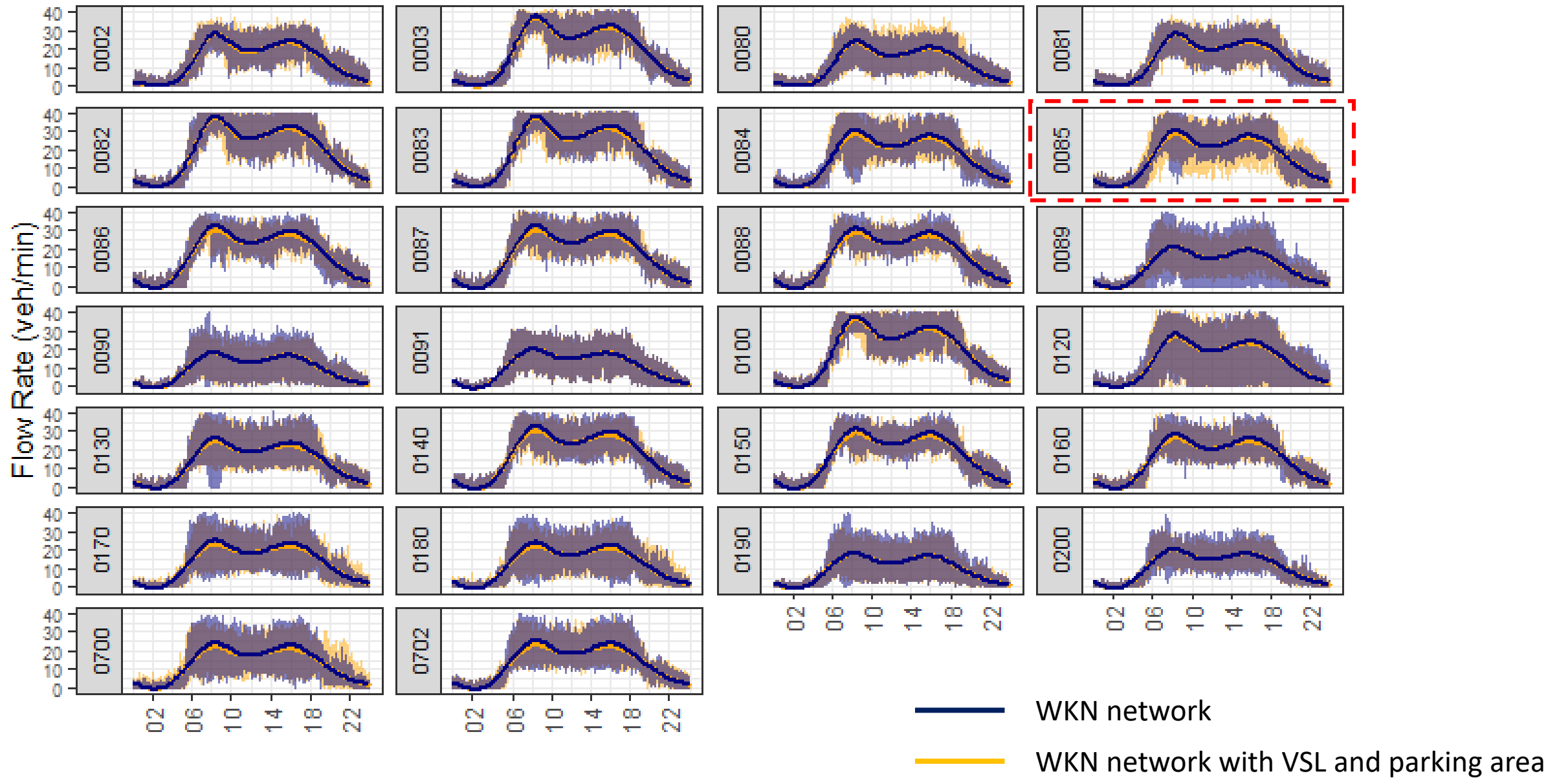
80.00 G

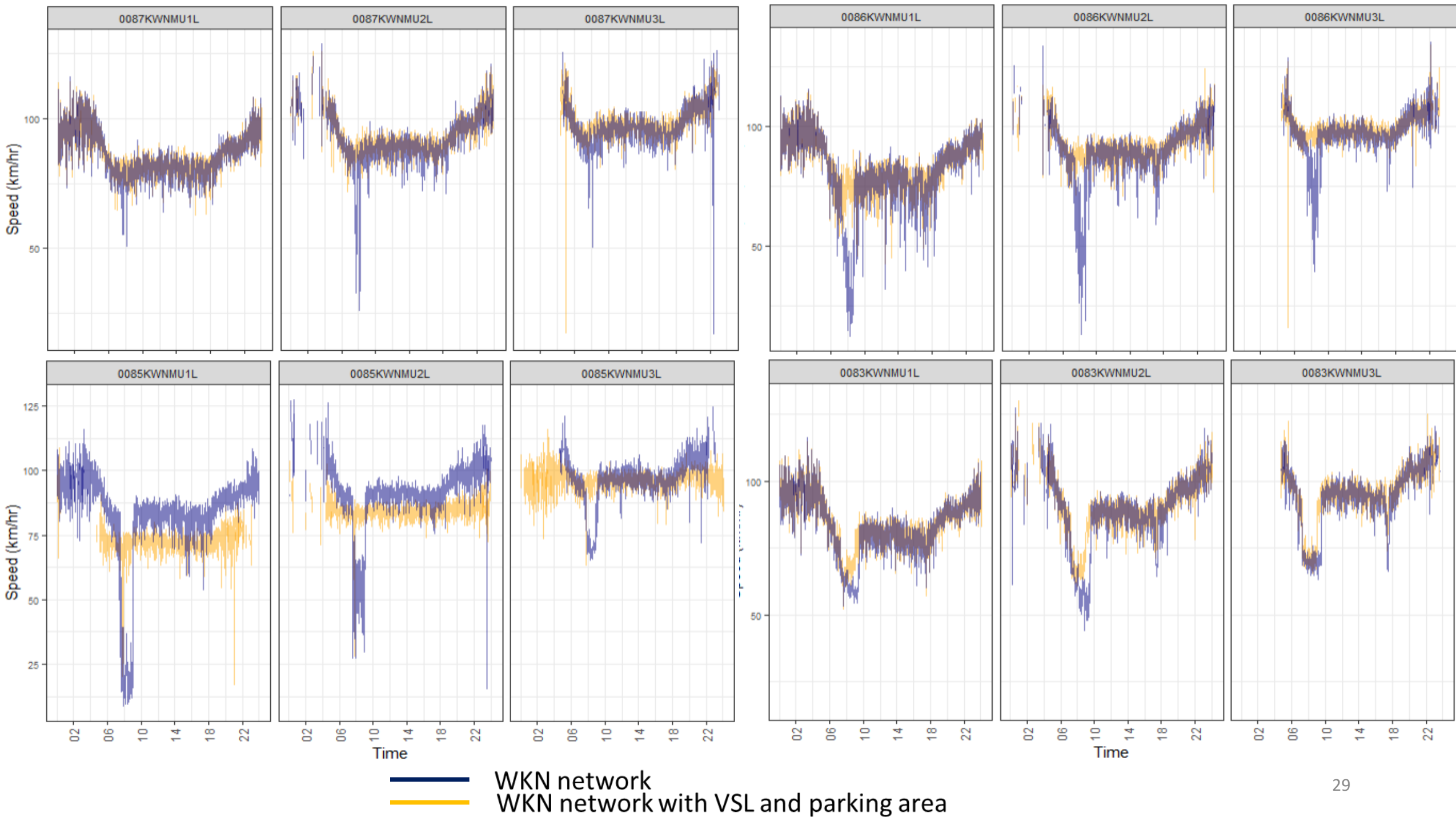
5.00 Y

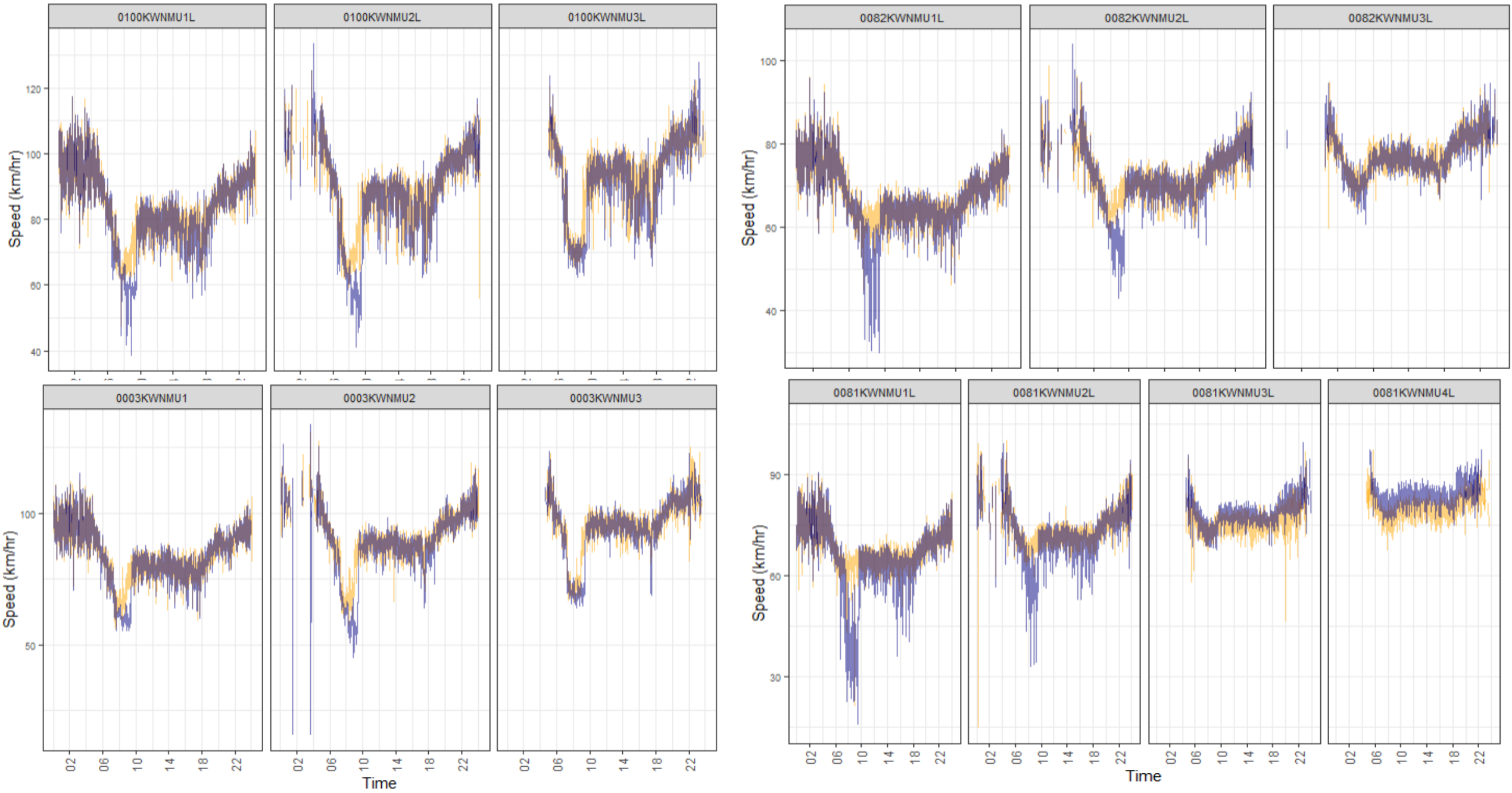
5.00 R

video









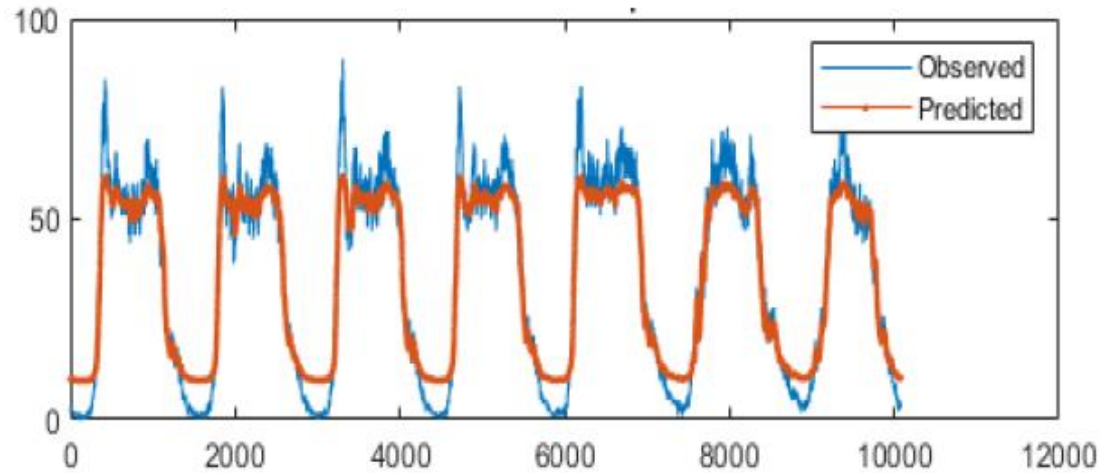
— WKN network
— WKN network with VSL and parking area



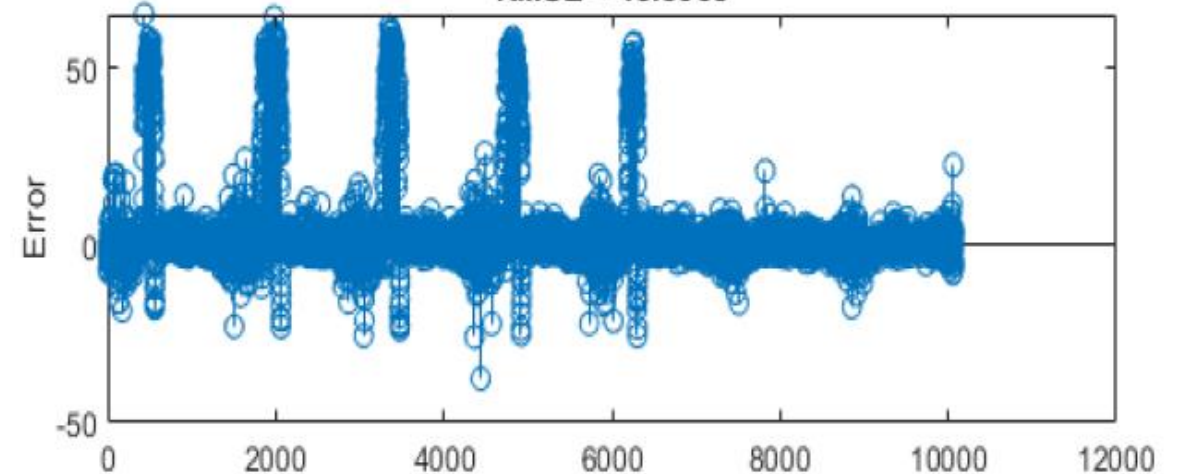
3 Data Analysis - link traffic prediction by BAM-LSTM

LSTM method (NPI 10)

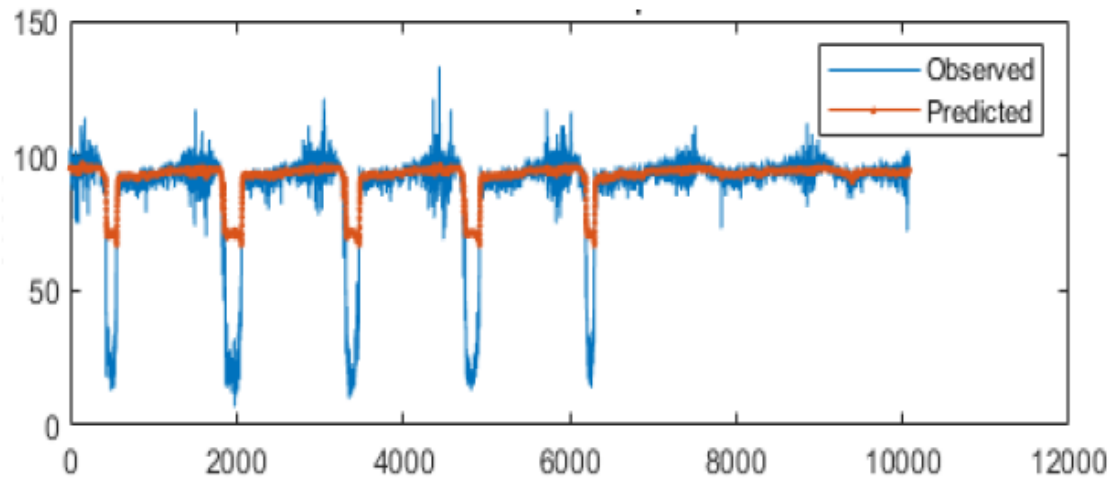
Flowrate (veh/min)



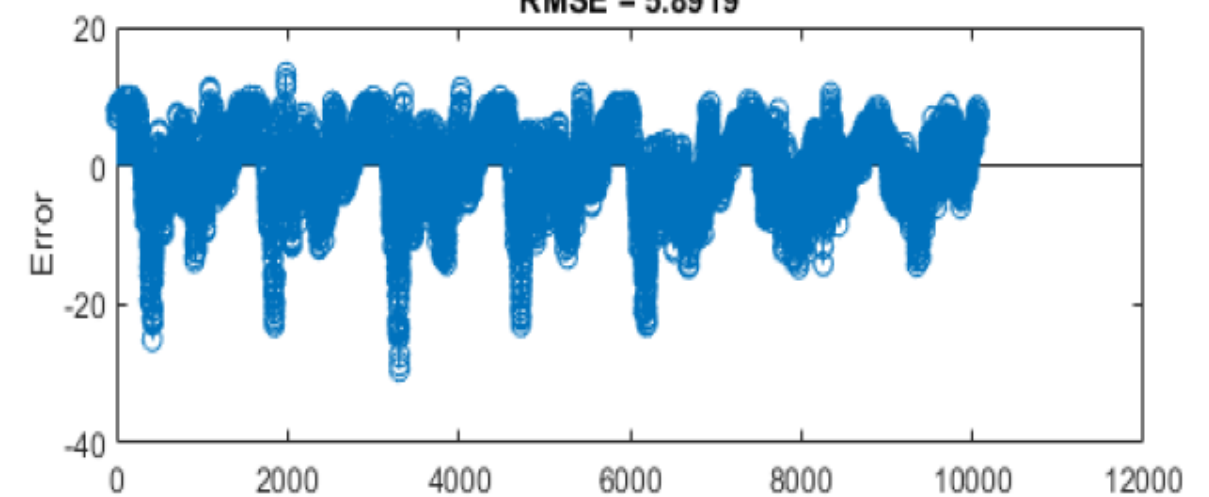
RMSE = 13.3065



Speed (km/hr)

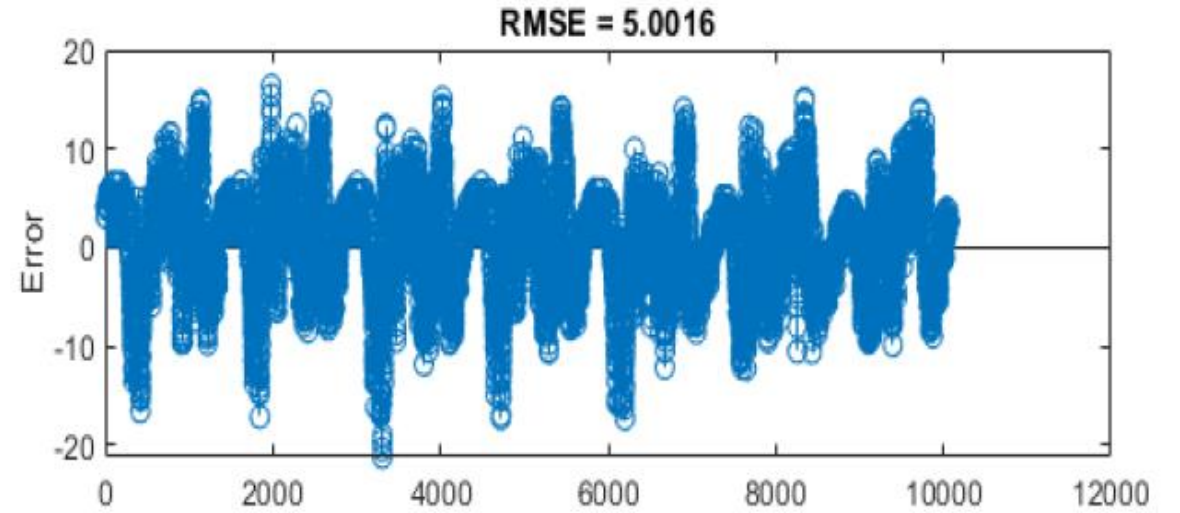
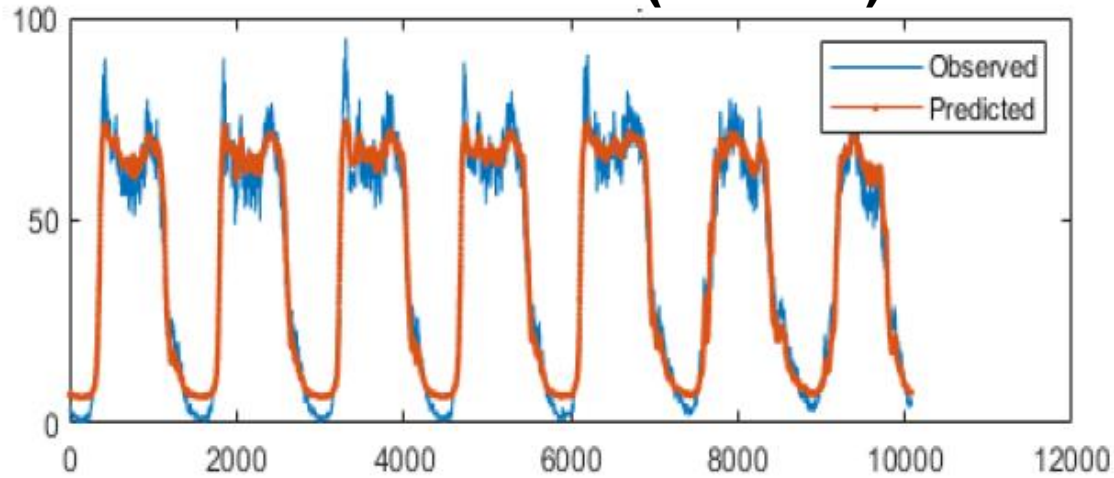


RMSE = 5.8919

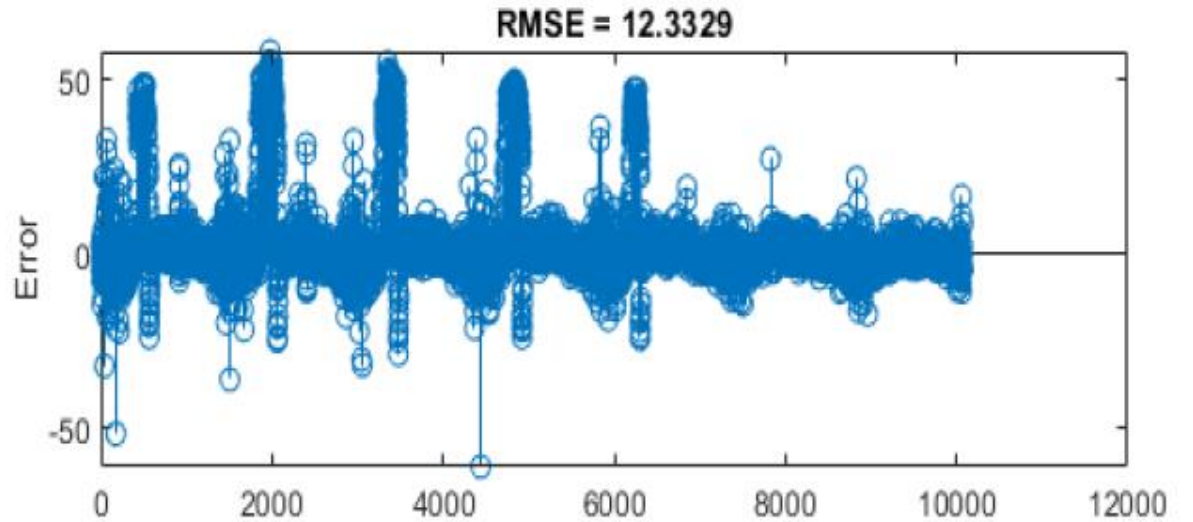
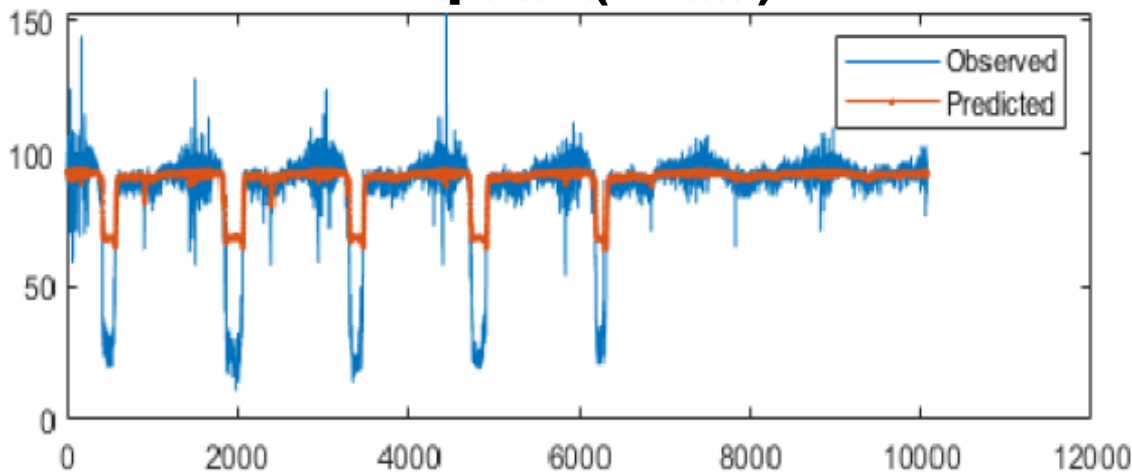


LSTM method (NPI 11)

Flowrate (veh/min)

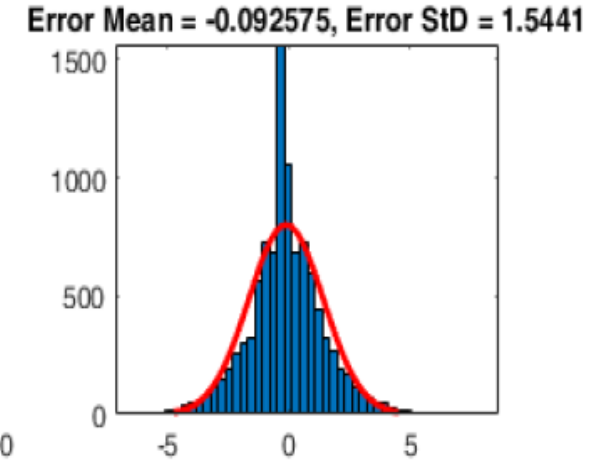
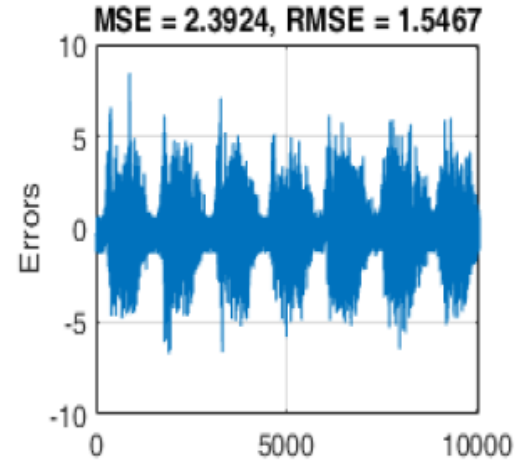
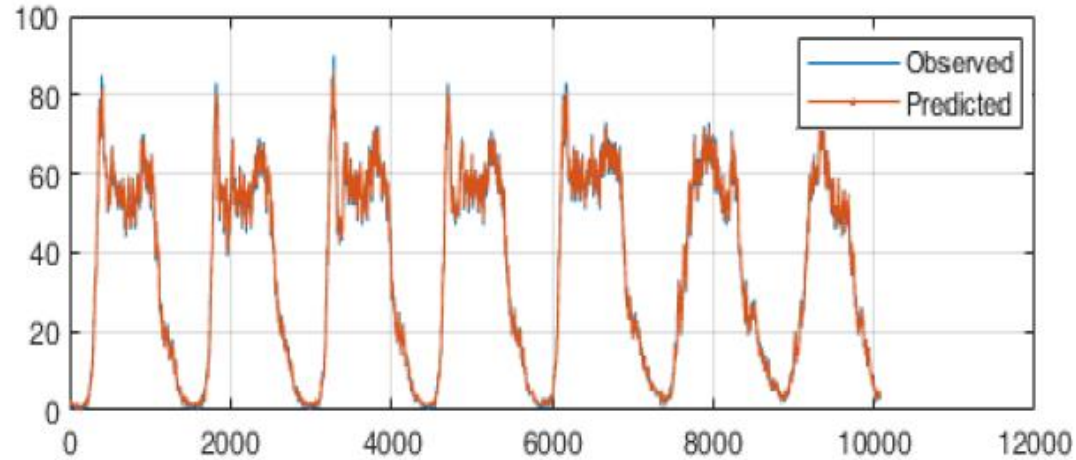


Speed (km/hr)

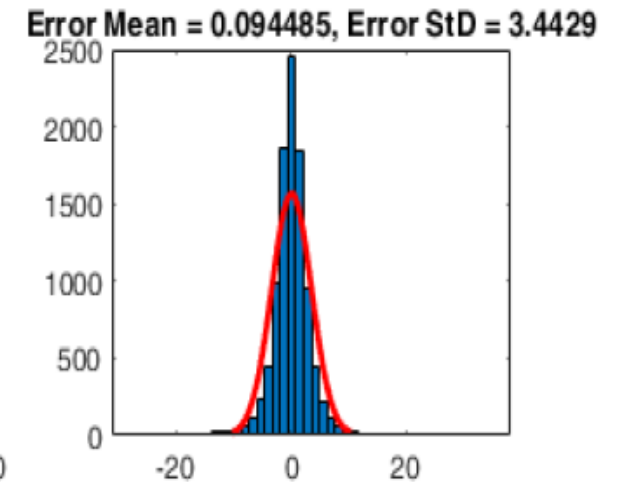
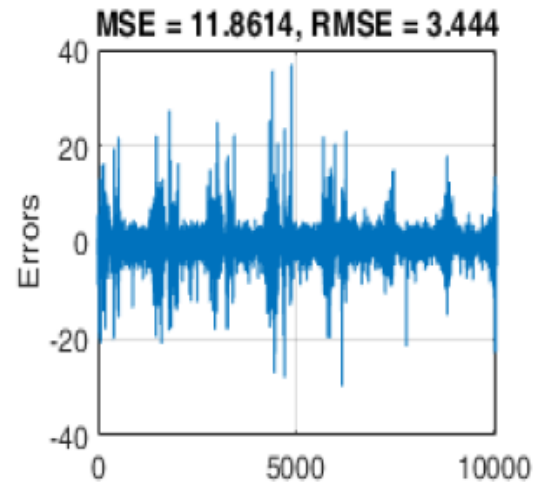
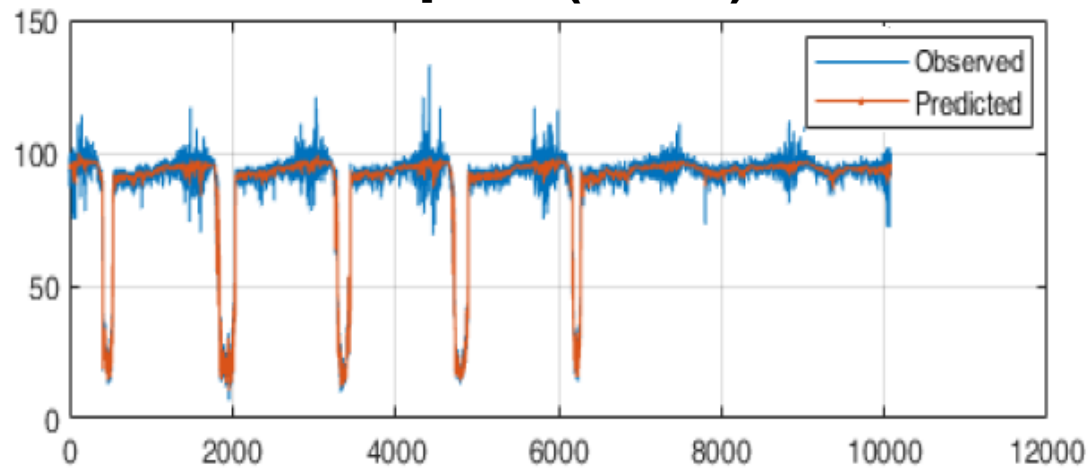


BAM-LSTM (NPI 10)

Flowrate (veh/min)



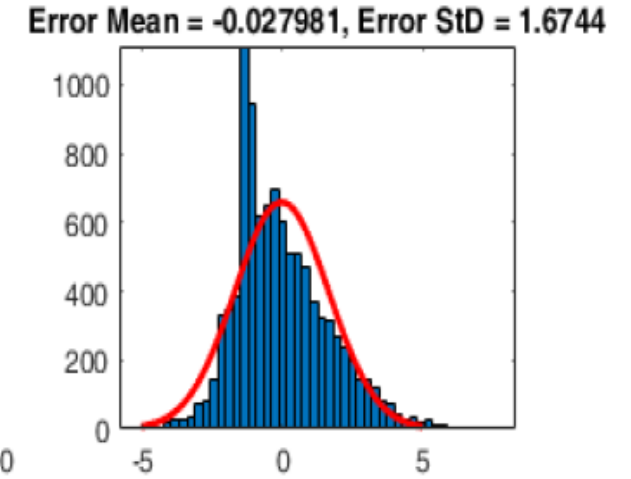
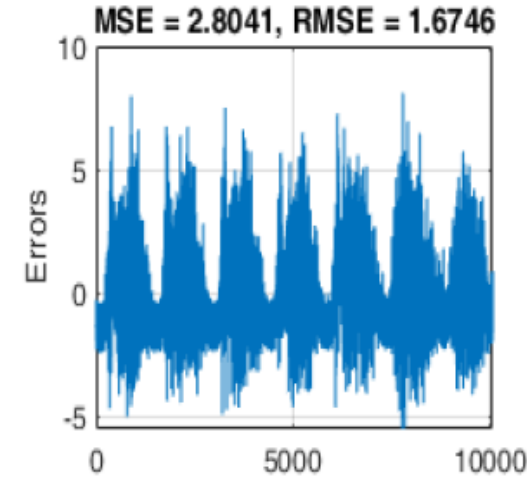
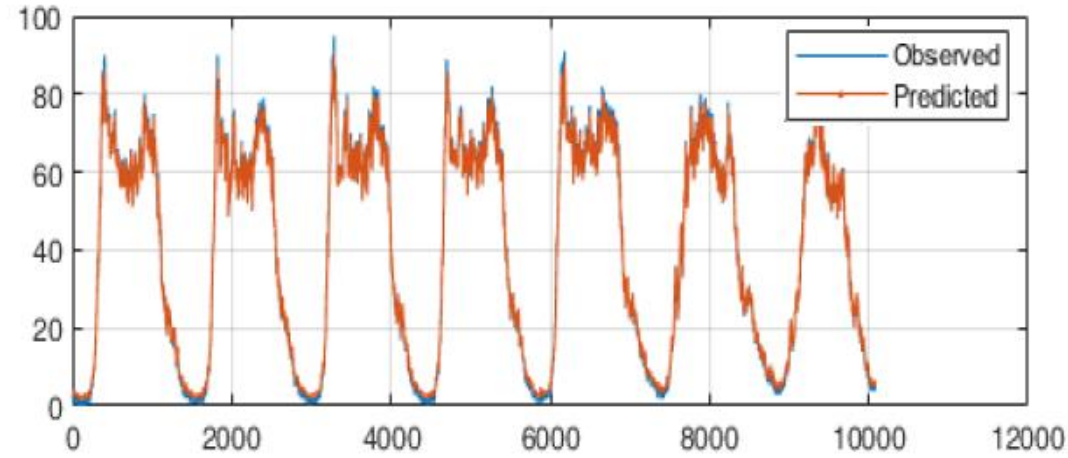
Speed (km/hr)



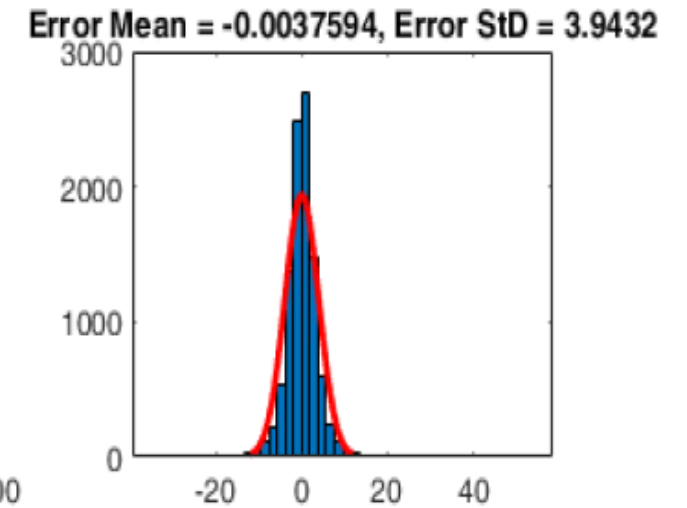
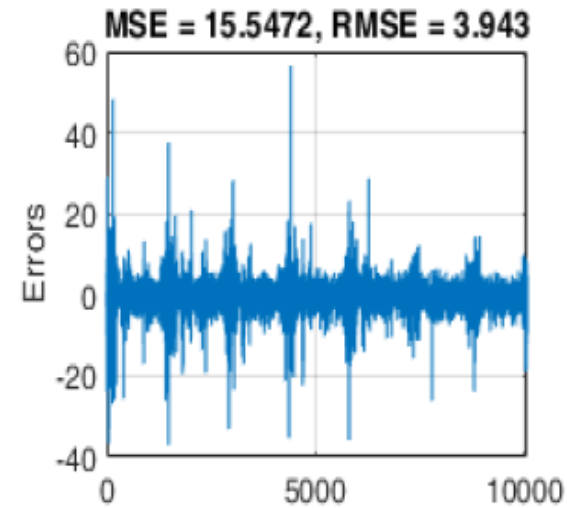
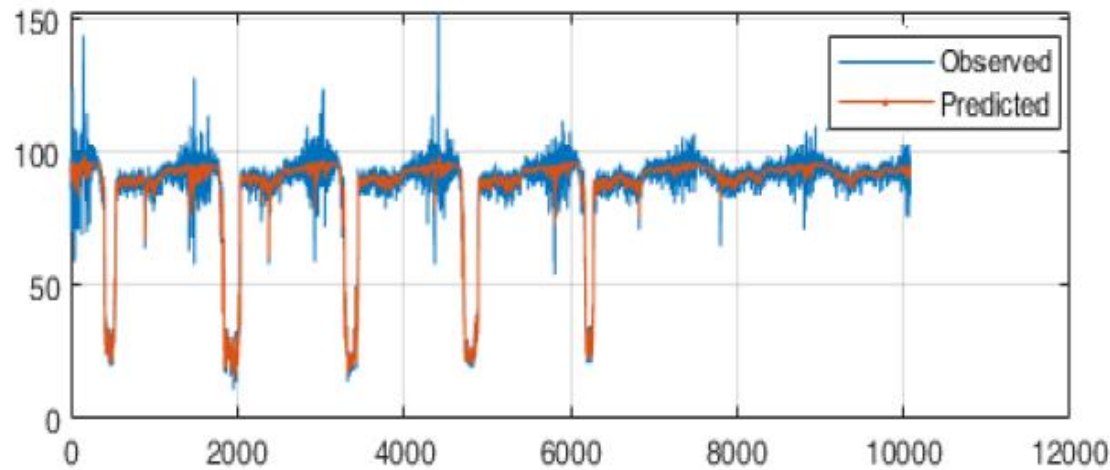
BAM-LSTM (NPI 11)



Flowrate (veh/min)



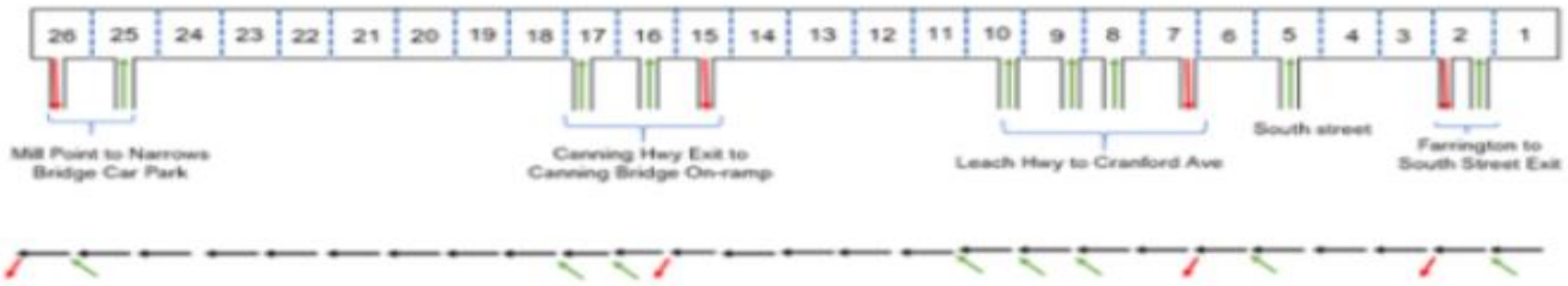
Speed (km/hr)



4 Optimization of Freeway Traffic Flow via Ramp Metering by CTM

PhD Student: C. Gu; Supervisors: YH Wu & B Wiwatanapataphee

13 km, 26 cells, 8 on-ramps, 4 off-ramps



CTM Traffic Model

Kinematic Wave Model:

$$\frac{\partial \rho_{x,t}}{\partial t} + \frac{\partial f_{x,t}}{\partial x} = r_{x,t} - s_{x,t},$$

Cell Transmission Model (CTM):

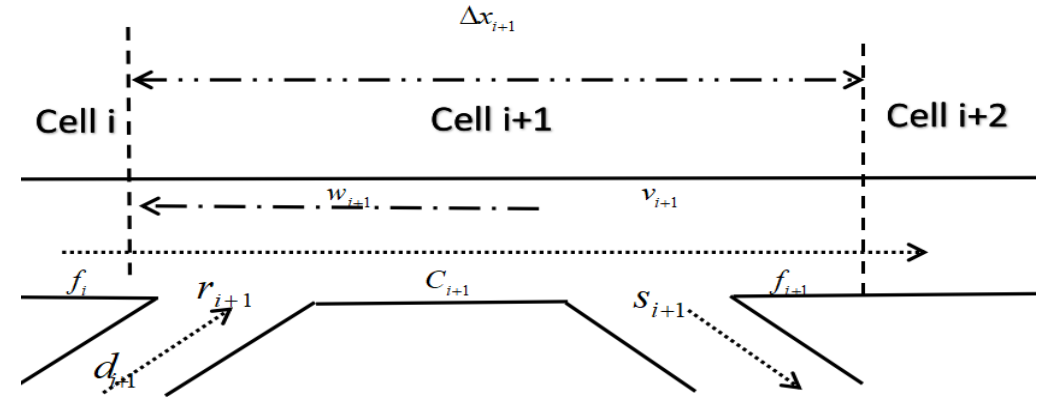
- Conservation equation:

$$\rho_{i,t+1} = \rho_{i,t} + \frac{\Delta t}{\Delta x_i} (f_{i-1,t} - f_{i,t} + r_{i,t} - s_{i,t}),$$

- Flow equation:

$$\begin{aligned} f_{i,t} &= \min\{v_i \rho_{i,t}, C_i, C_{i+1}, w_{i+1}(\rho_{\max,i+1} - \rho_{i,t})\} \\ &= \min\{\min\{v_i \rho_{i,t}, C_i\}, \min\{C_{i+1}, w_{i+1}(\rho_{\max,i+1} - \rho_{i+1,t})\}\} = \min\{f_{i,t}^D, f_{i+1,t}^S\}, \quad \forall i,t \end{aligned}$$

- onramp: $q_{i,t+1} = q_{i,t} + \Delta t(d_{i,t} - r_{i,t})$



Deterministic Optimization Model

$$\text{(DP) } \min_r D = \sum_{i=1}^I \sum_{t=1}^T (\rho_{i,t} \Delta x_i \Delta t - \frac{f_{i,t} \Delta x_i \Delta t}{v_i}) + \sum_{j=1}^J \sum_{t=1}^T q_{j,t} \Delta t,$$

subject to:
$$\rho_{i,t+1} = \rho_{i,t} + \frac{\Delta T}{\Delta L_i} (f_{i,t} - f_{i,t} - \frac{P_i}{1 - P_i} f_{i,t} + r_{i,t}) \quad (1)$$

$$q_{i,t+1} = q_{i,t} + \Delta T (d_{i,t} - r_{i,t}) \quad (2)$$

$$f_{i,t} \leq (1 - P_i) v_{f,i} \rho_{i,t}, \quad (3)$$

$$f_{i,t} \leq (1 - P_i) [v_{f,i} \rho_{i,t} + \alpha v_{f,i} \rho_{i,t} (\frac{\rho_{i,t} - \rho_{cr,i}}{\rho_{cr,i} - \rho_{max,i}})], \quad (4)$$

$$f_{i,t} \leq v_{f,i+1} \rho_{cr,i+1} - \theta_r r_{i+1,t}, \quad (5)$$

$$f_{i,t} \leq w_{i+1} (\rho_{max,i+1} - \rho_{i+1,t}) - \theta_r r_{i+1,t}. \quad (6)$$

$$q_{i,t} \leq q_{max,i}, \quad (7)$$

$$r_{i,t} \leq r_{max,i}. \quad (8)$$

Distributionally robust constraints

Consider uncertain demand flows :
$$\inf_{\mathbb{P} \in \mathcal{P}} \mathbb{P}(q_{j,t} - q_{max} \leq 0) \geq \varepsilon_d, \forall j, t, \quad (9)$$

By the above relationship (9), the relationships (2) and (7) can be simplified as follows:

$$\inf_{\mathbb{P} \in \mathcal{P}} \mathbb{P}\left\{q_{j,0} - \sum_{l=0}^{t-1} r_{j,l} \Delta t - q_{max} + \mathbf{B}_{t-1}^\top \tilde{\mathbf{d}}_j \leq 0\right\} \geq 1 - \varepsilon_d, \forall j, t. \quad (10)$$

An approximation approach proposed by Calafiore and El Ghaoui [10] is utilized to approximate the distributionally robust chance constraint (10) in this section.

Distributionally robust optimization model

$$\begin{aligned}
 (\text{DRCCP}) \min_r D &= \sum_{i=1}^I \sum_{t=1}^T \left(\left[\rho_{i,1} + \sum_{l=0}^{t-1} \frac{\Delta t}{\Delta x_i} (f_{i-1,l} - f_{i,l} + r_{i,l} - s_{i,l}) \right] \Delta x_i \Delta t - \frac{f_{i,t} \Delta x_i \Delta t}{v_i} \right) \\
 &+ \mathbb{E} \left[\sum_{j=1}^J \sum_{t=1}^T \left(q_{j,1} - \sum_{l=0}^{t-1} r_{j,l} \Delta t + B_{t-1}^\top \tilde{\mathbf{d}}_j \right) \Delta t \right],
 \end{aligned}$$

subject to:
$$\rho_{i,t+1} = \rho_{i,t} + \frac{\Delta T}{\Delta L_i} (f_{i,t} - f_{i,t} - \frac{P_i}{1 - P_i} f_{i,t} + r_{i,t})$$

$$f_{i,t} \leq (1 - P_i) v_{f,i} \rho_{i,t},$$

$$f_{i,t} \leq (1 - P_i) \left[v_{f,i} \rho_{i,t} + \alpha v_{f,i} \rho_{i,t} \left(\frac{\rho_{i,t} - \rho_{cr,i}}{\rho_{cr,i} - \rho_{max,i}} \right) \right],$$

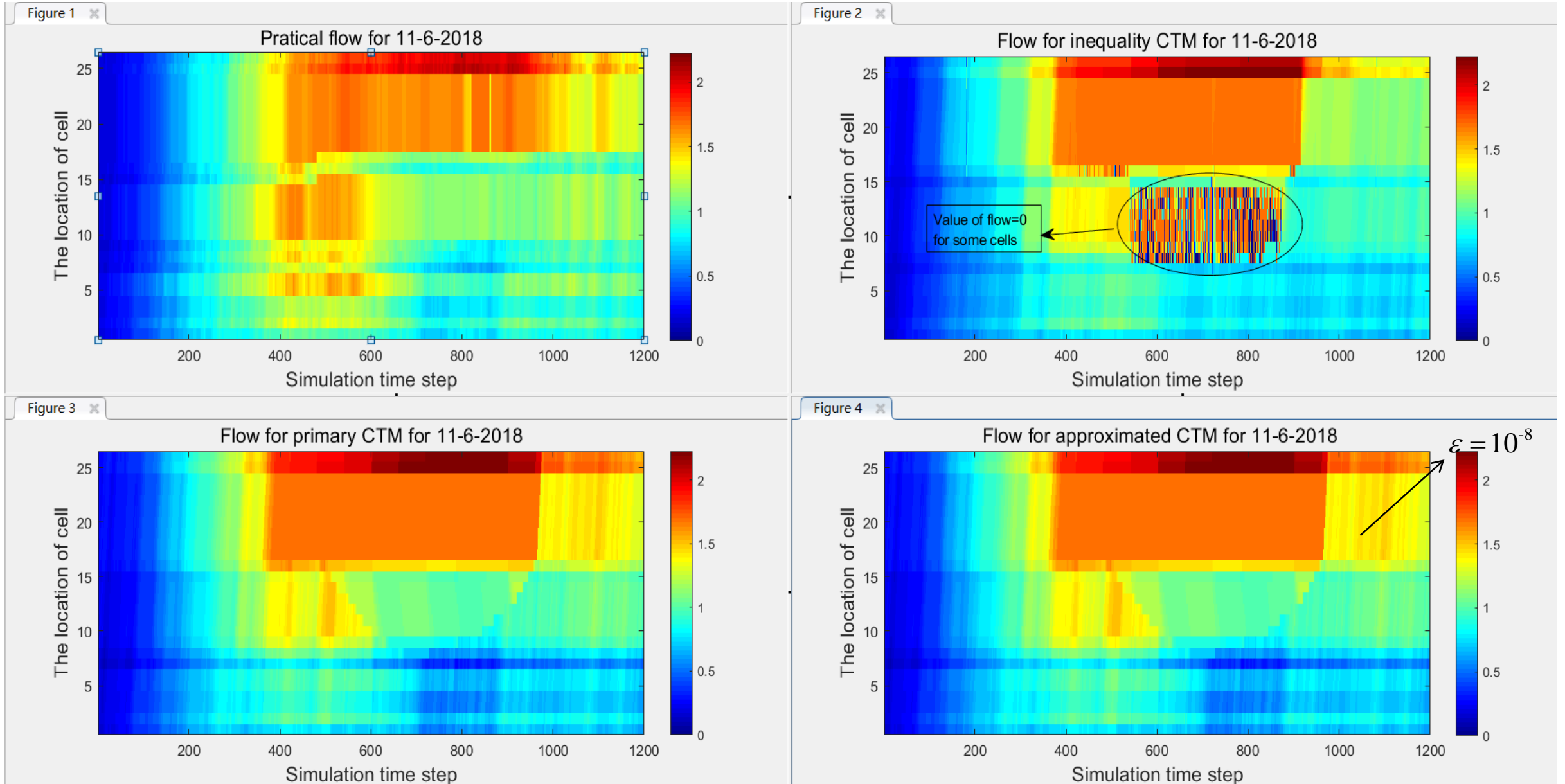
$$f_{i,t} \leq v_{f,i+1} \rho_{cr,i+1} - \theta_r r_{i+1,t},$$

$$f_{i,t} \leq w_{i+1} (\rho_{max,i+1} - \rho_{i+1,t}) - \theta_r r_{i+1,t}.$$

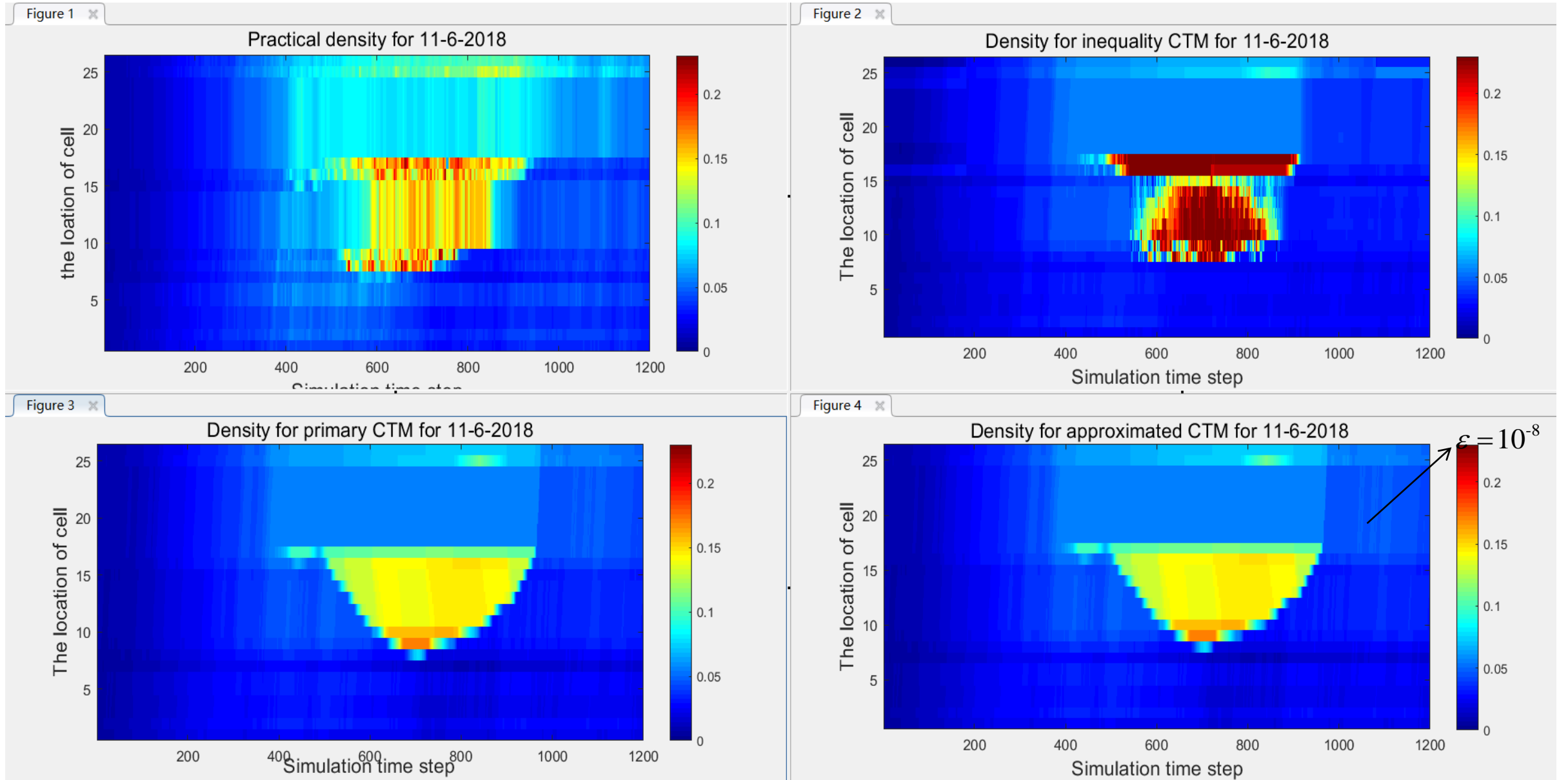
$$r_{i,t} \leq r_{max,i}.$$

$$\kappa_{\epsilon_d} \sigma(B) + \bar{\Psi}(B) \leq 0, \quad \kappa_{\epsilon_d} = \sqrt{\frac{1 - \epsilon_d}{\epsilon_d}}, \quad \forall j, t.$$

Numerical Results



Numerical Results



thank
you

