On Simulation and Optimization of Freeway Network Operations

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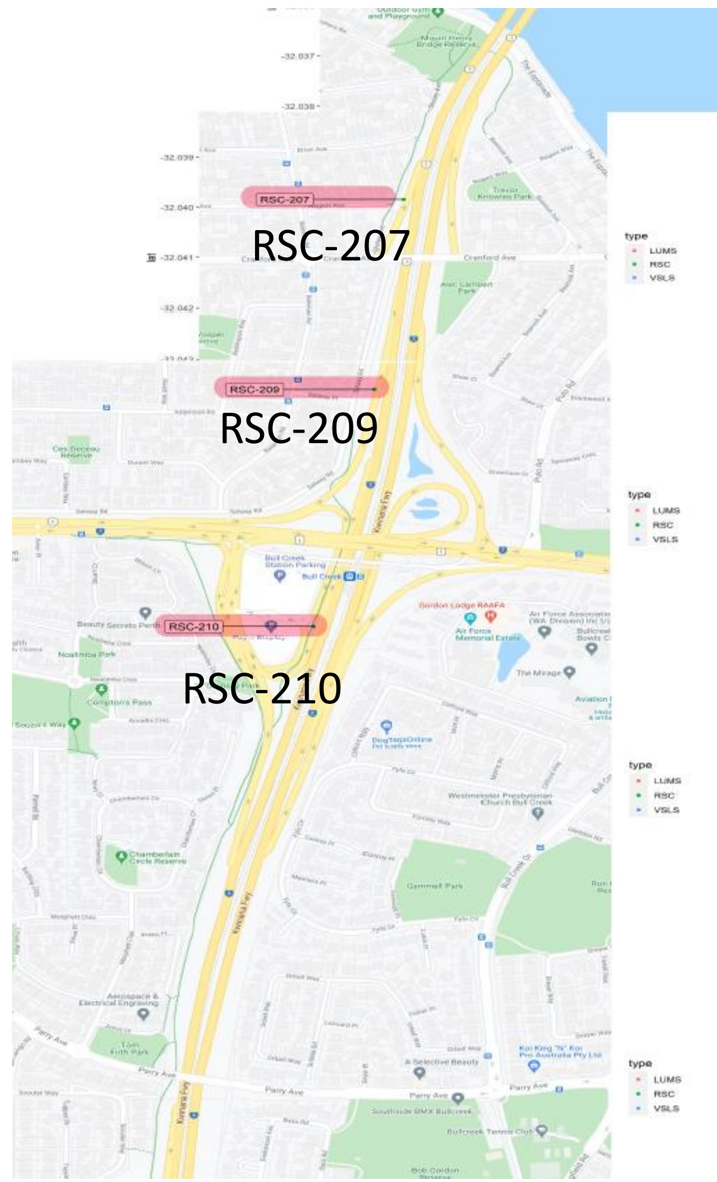
Progress from last PSG meeting

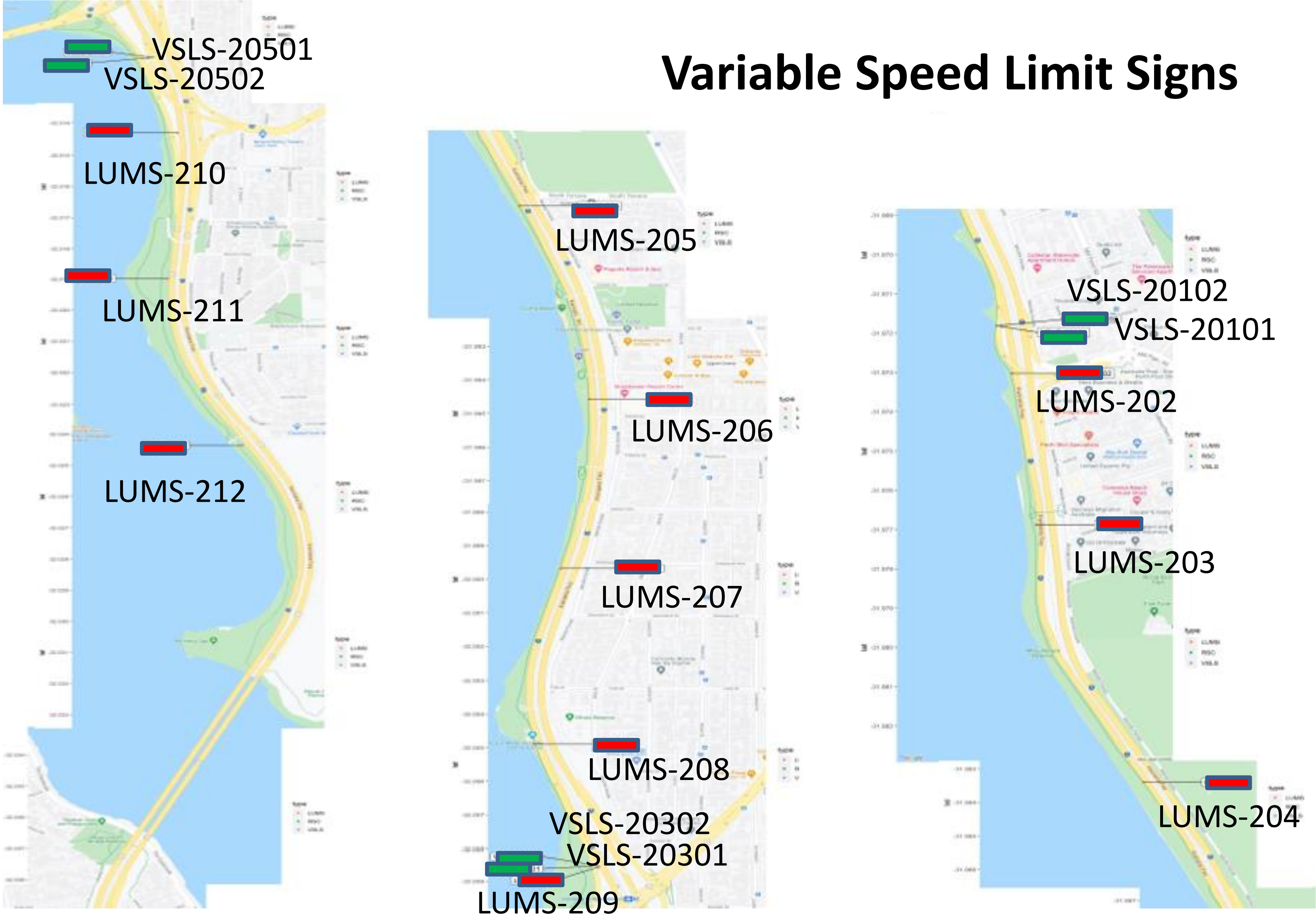
- Computer implementation of ramp metering and VSL on the Kwinana freeway traffic flow simulation model
- Further data analysis: traffic prediction by LSTM & BAM-LSTM methods
- Optimization of freeway traffic flow via ramp metering

1. Computer implementation of ramp metering and VSL on the Kwinana freeway traffic flow simulation model

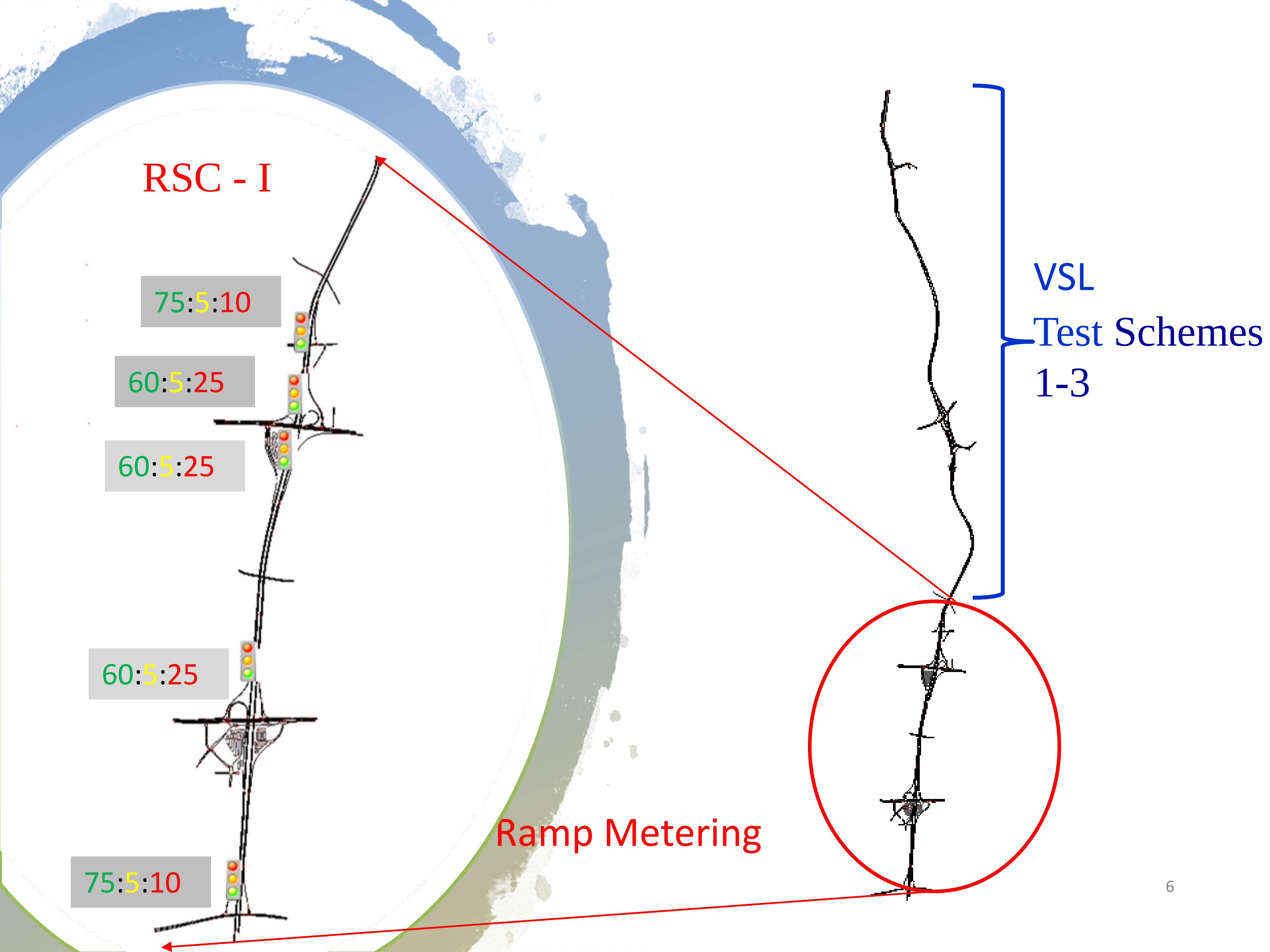
Ramp Metering Series



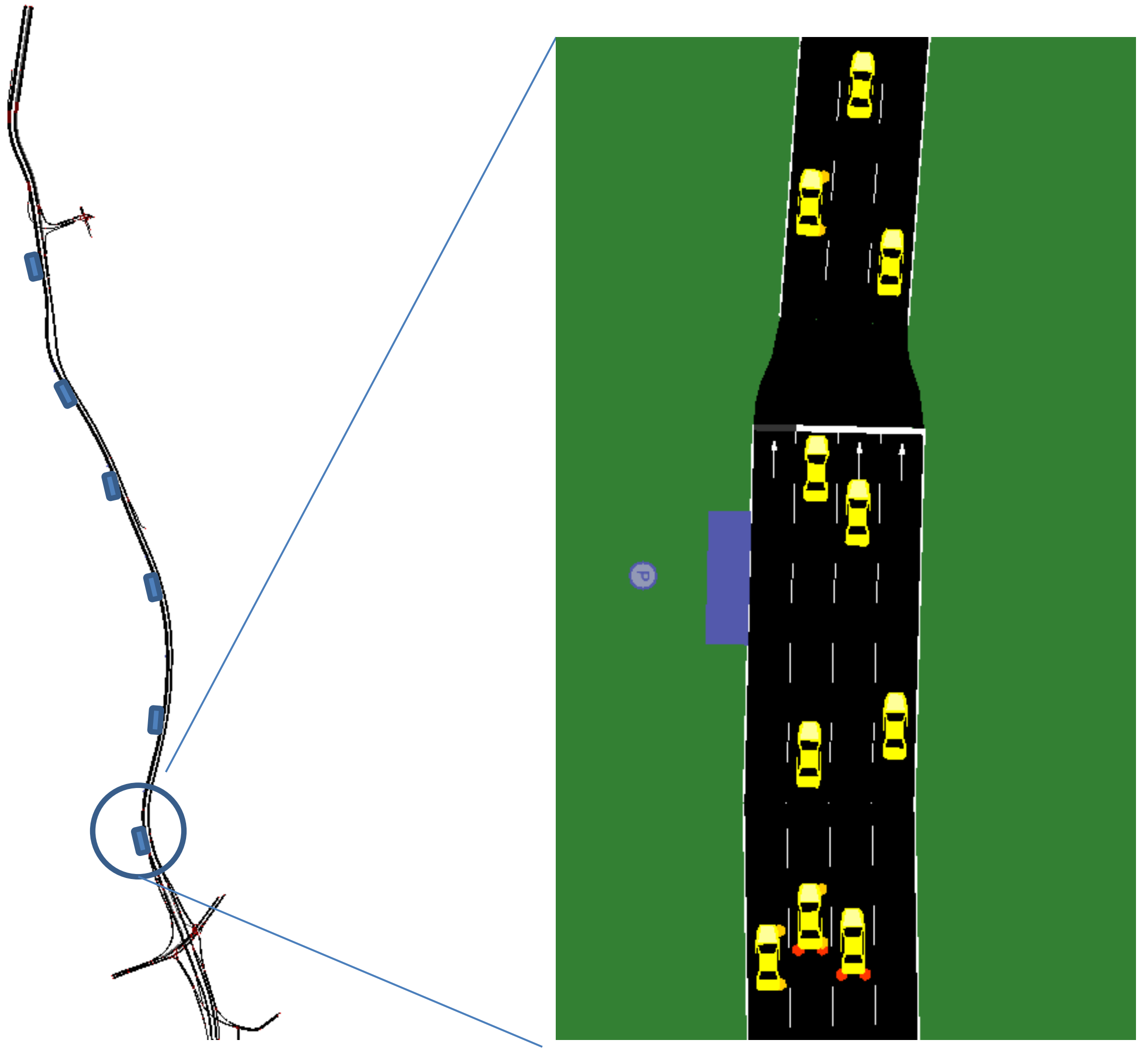
Variable Speed Limit Signs



VSLS
LUMS


RSC - I
75:5:10
60:5:25
60:5:25
60:5:25
75:5:10
Ramp Metering
VSL
Test Schemes
1-3

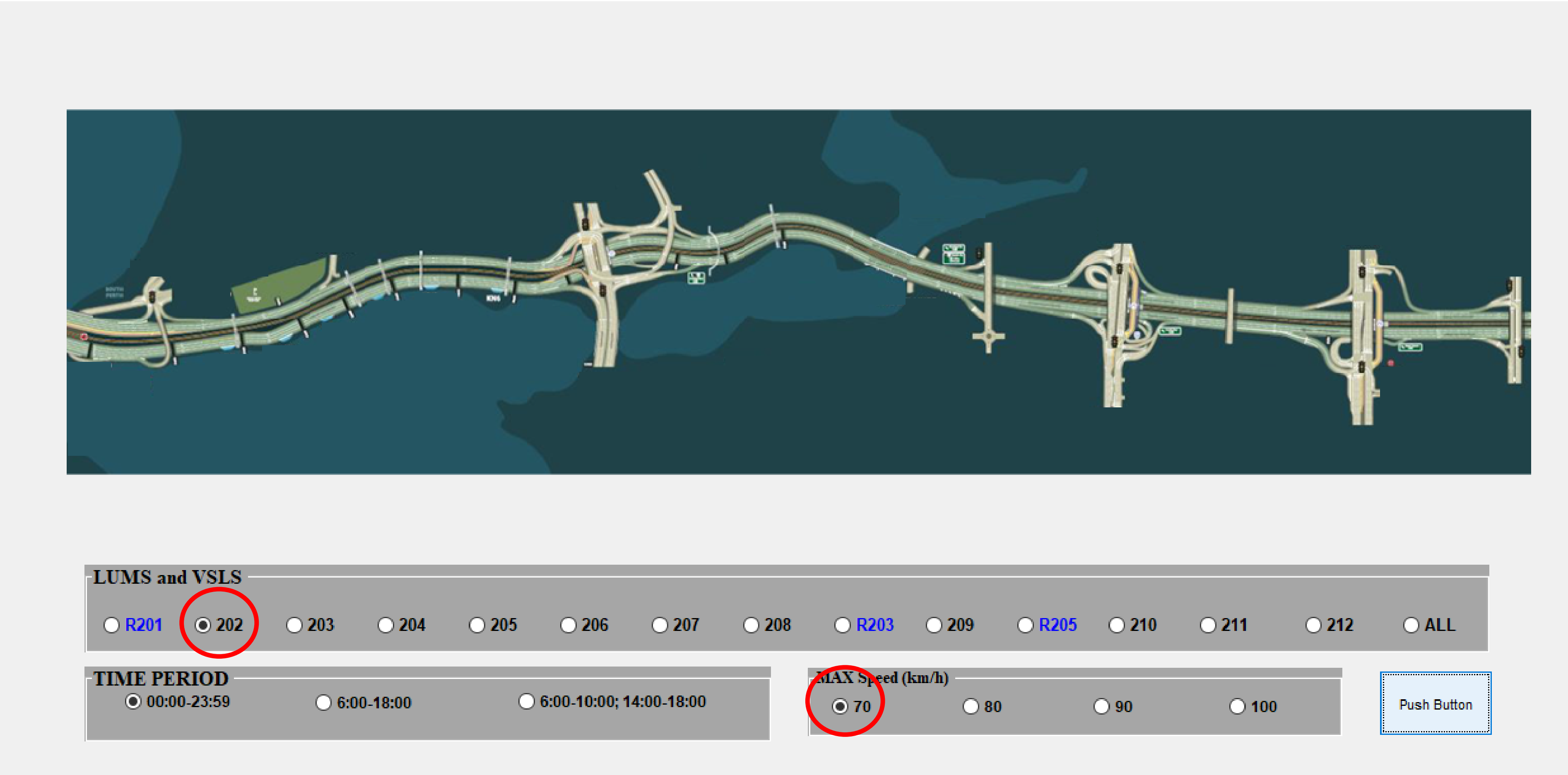
6 Parking areas

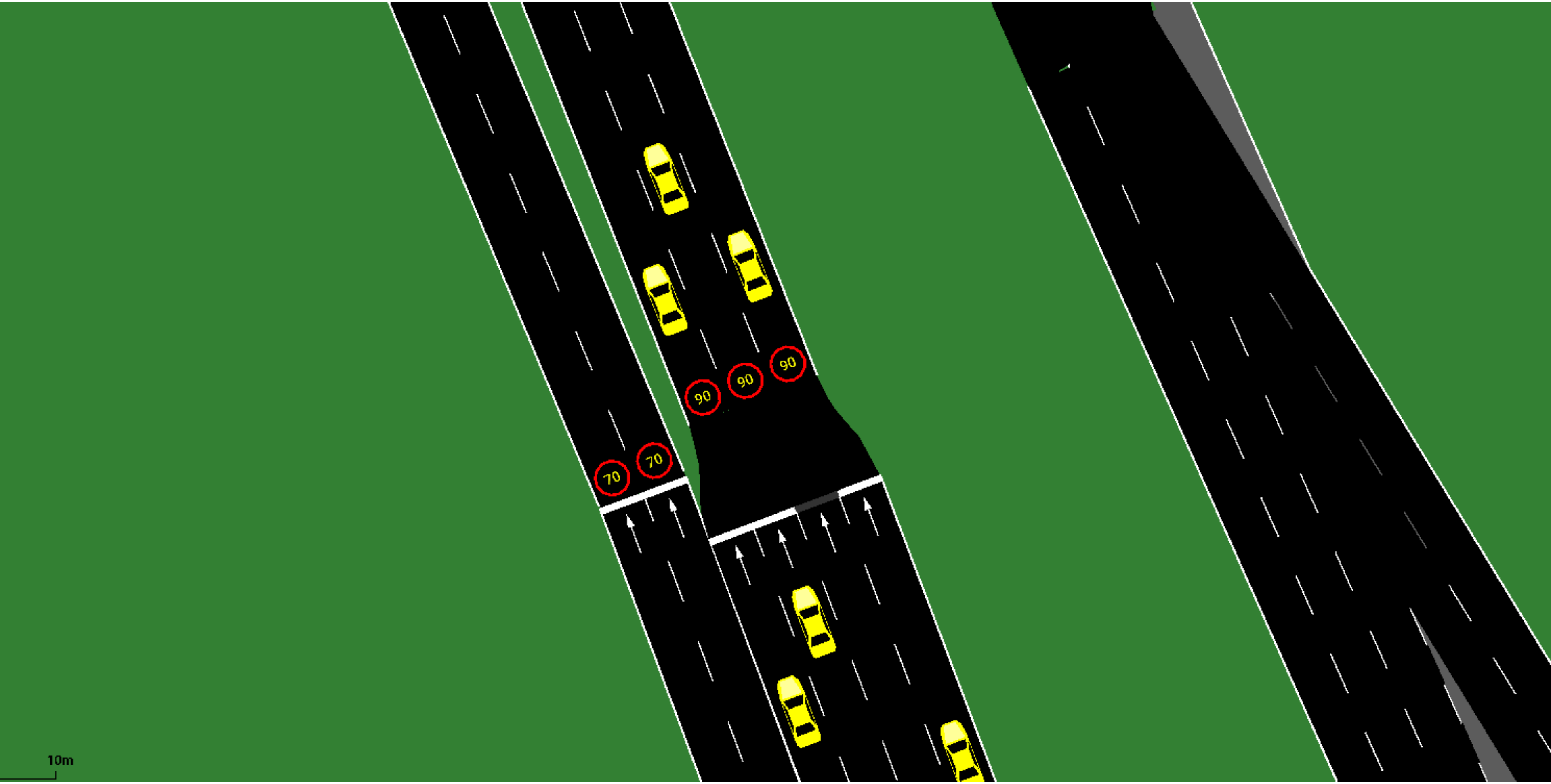


Numerical Test Schemes
VSL Period: 6:00-10:00; 14:00-18:00

VSL Scheme	Ramp Metering (90 sec per cycle)	LUMS Speed	VSLS Speed
1	80 G| 5 Y| 5 R	90	70
2	80 G| 5 Y| 5 R	100	70
3	RSC - I	90	70
4	RSC - I	100	70

VSL Application Design

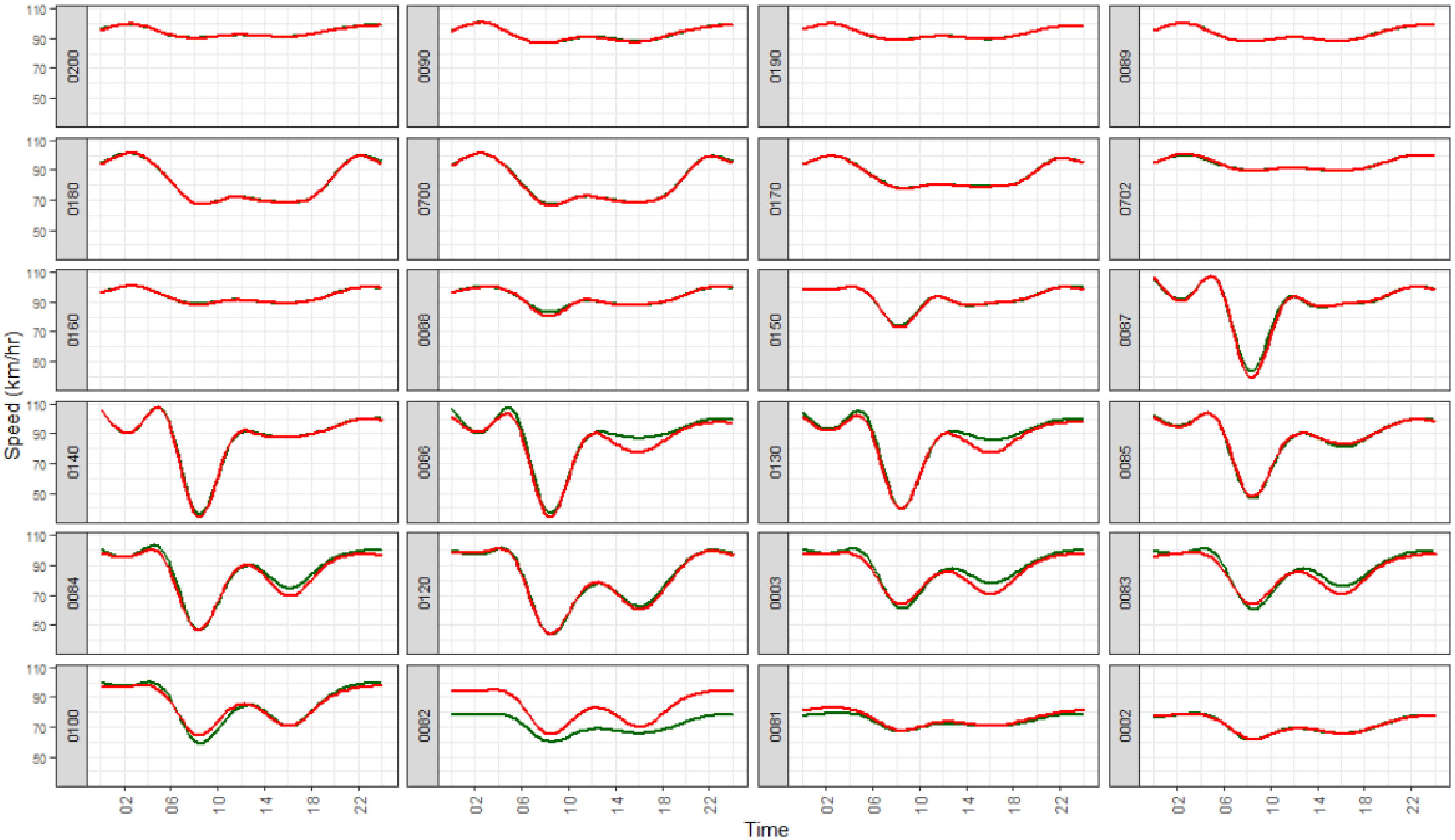




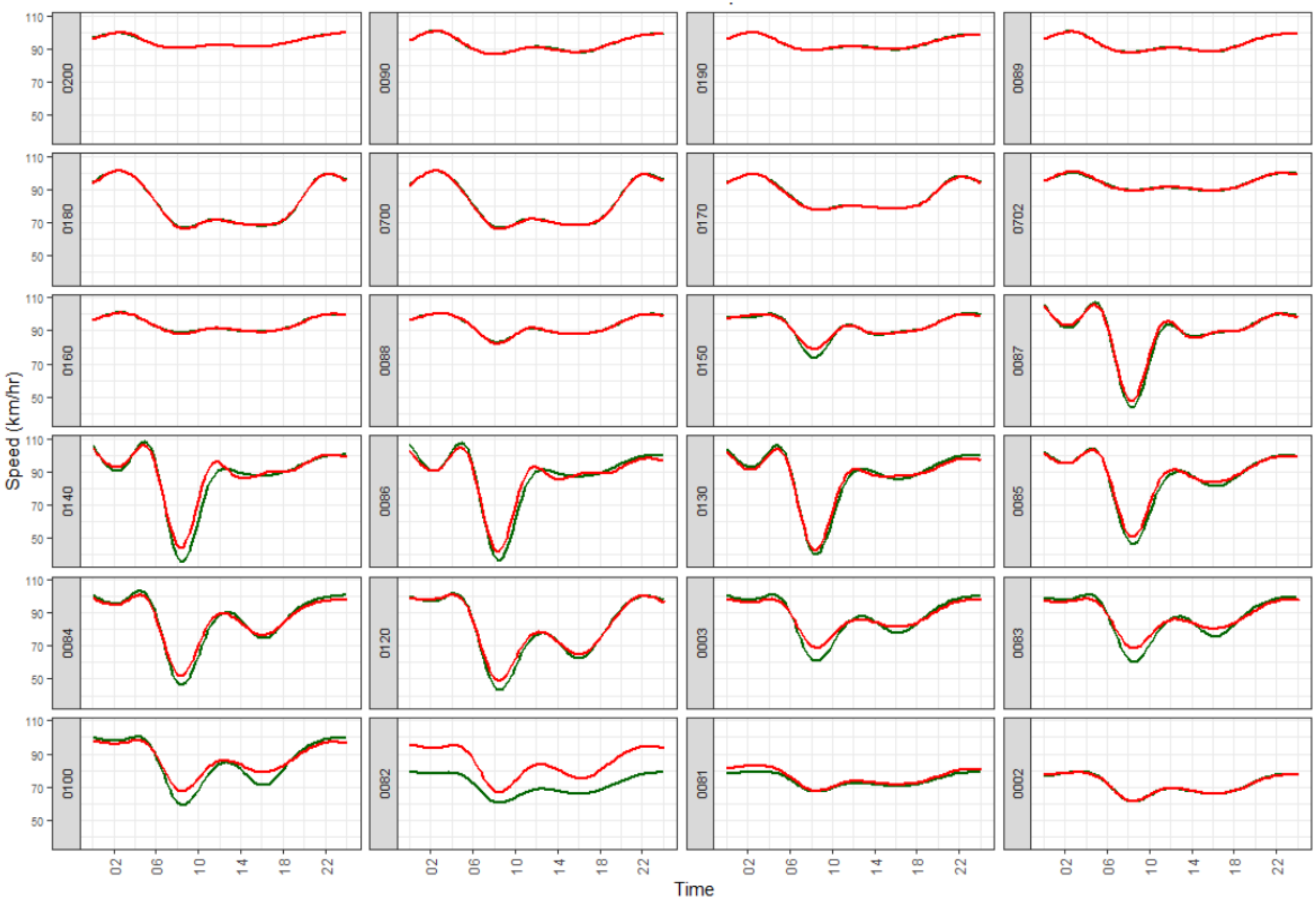
VSLS (70 km/h) and LUMS (90 km/h)


Microsimulation
Cassey St
McDougall St
Bus Ln
Canning Hwy
Edgecumbe St
Tulip Ln
Manning Rd
1
2
6

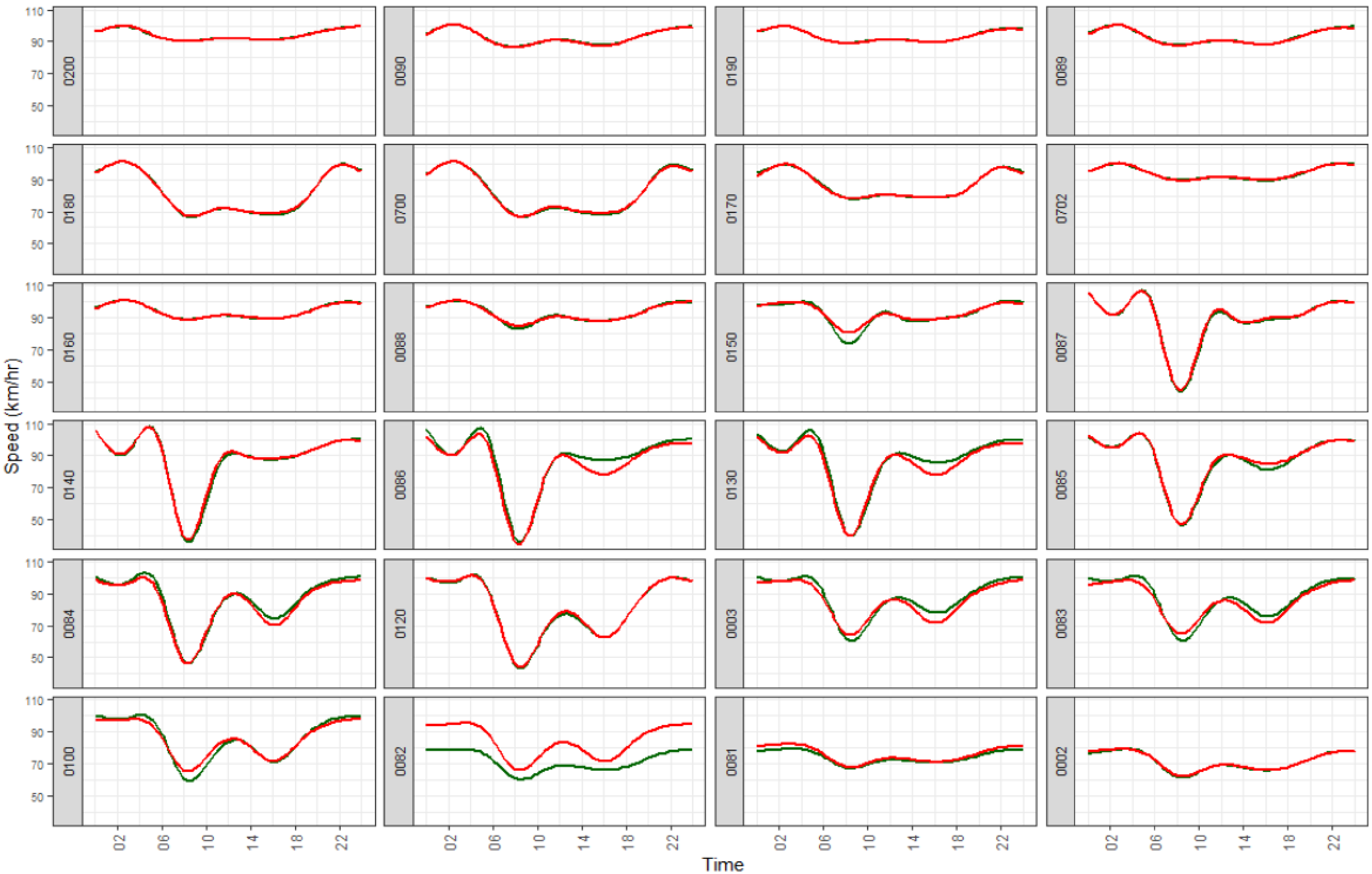
LUMS 90 & VSLS 70



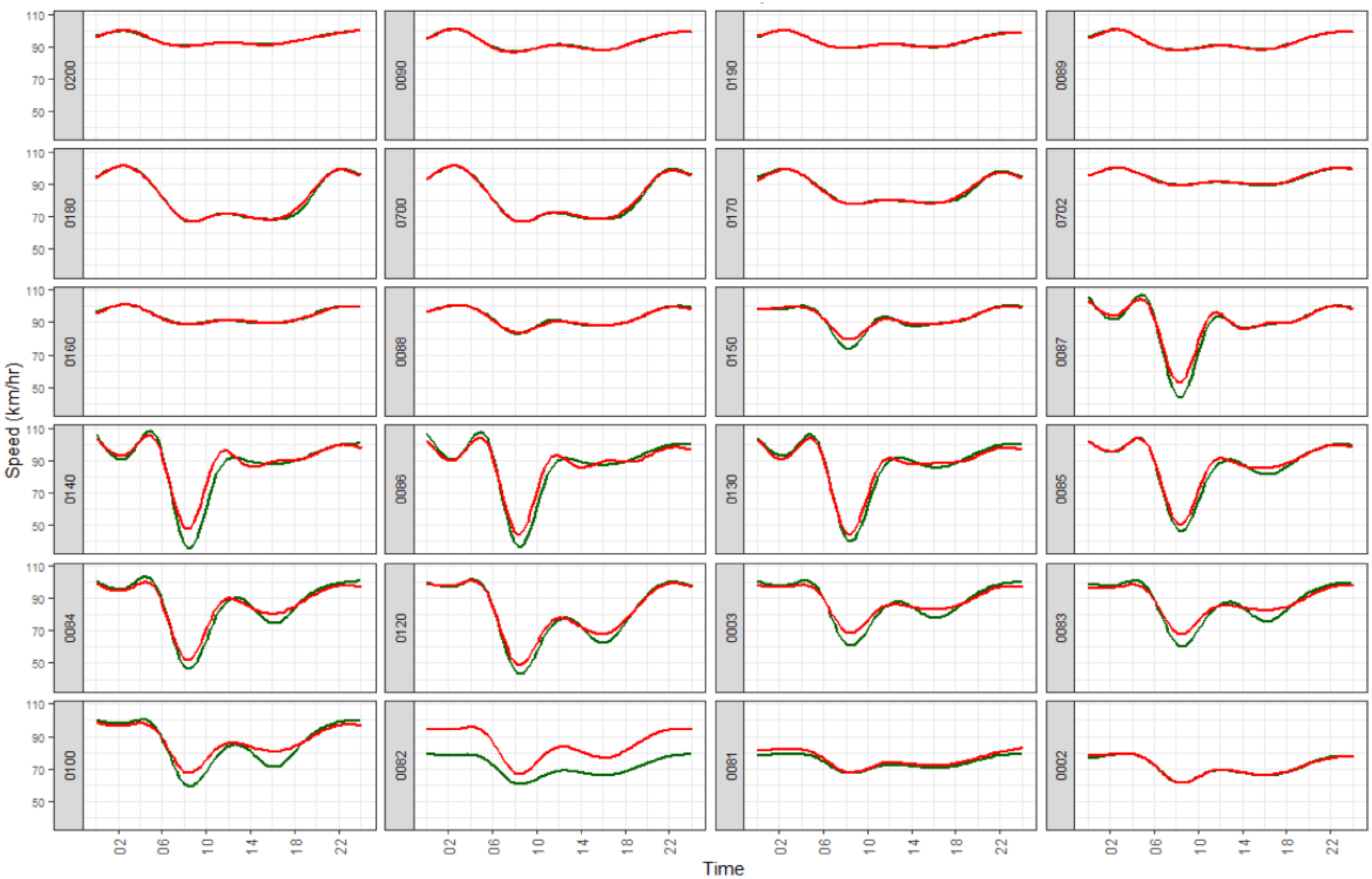
LUMS 100 & VSLS 70

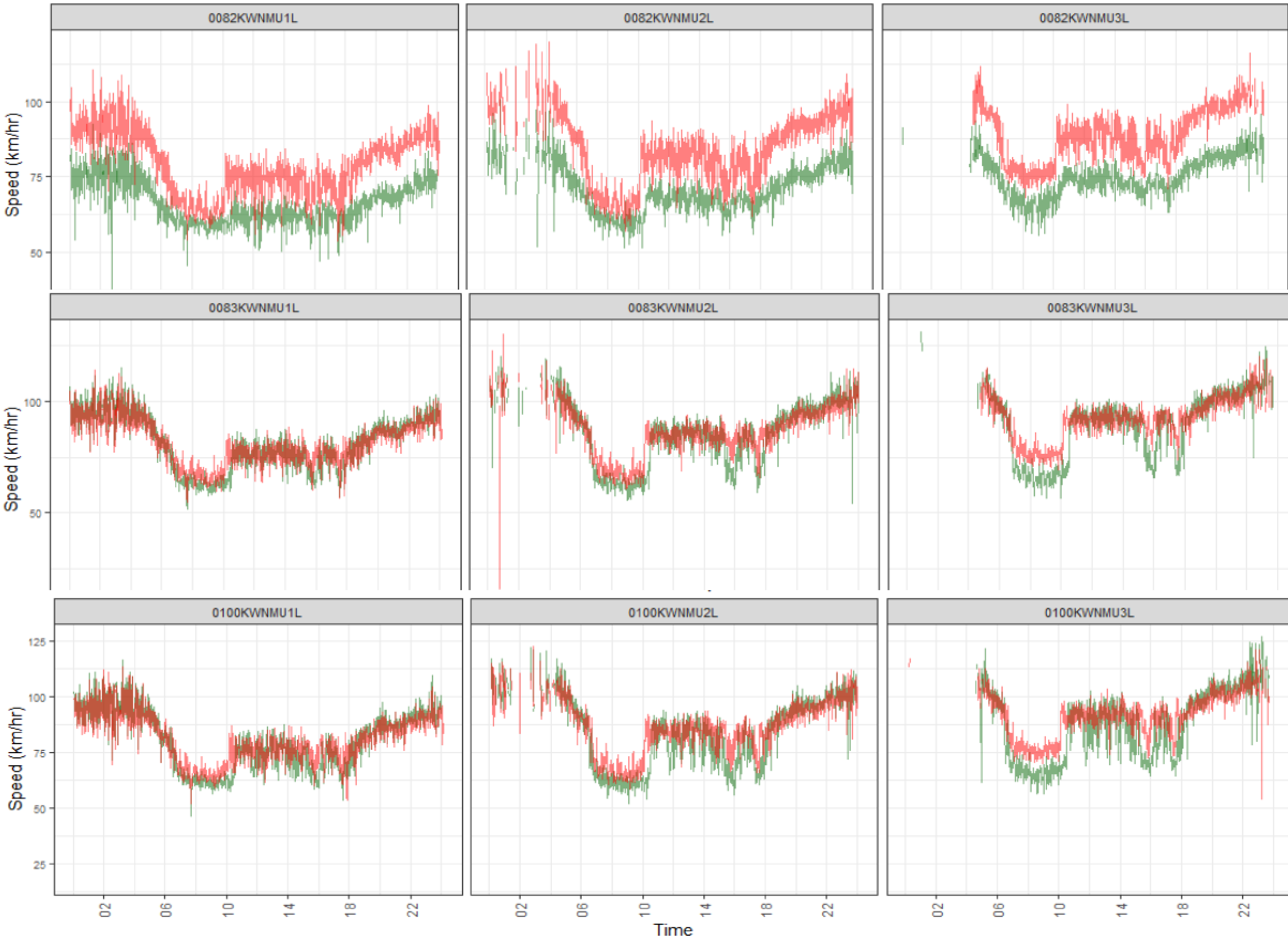


LUMS 90 & VSLS 70 & RSC1 (from 6 AM)



LUMS 100 & VSLS 70 && RSC (from 6 AM)

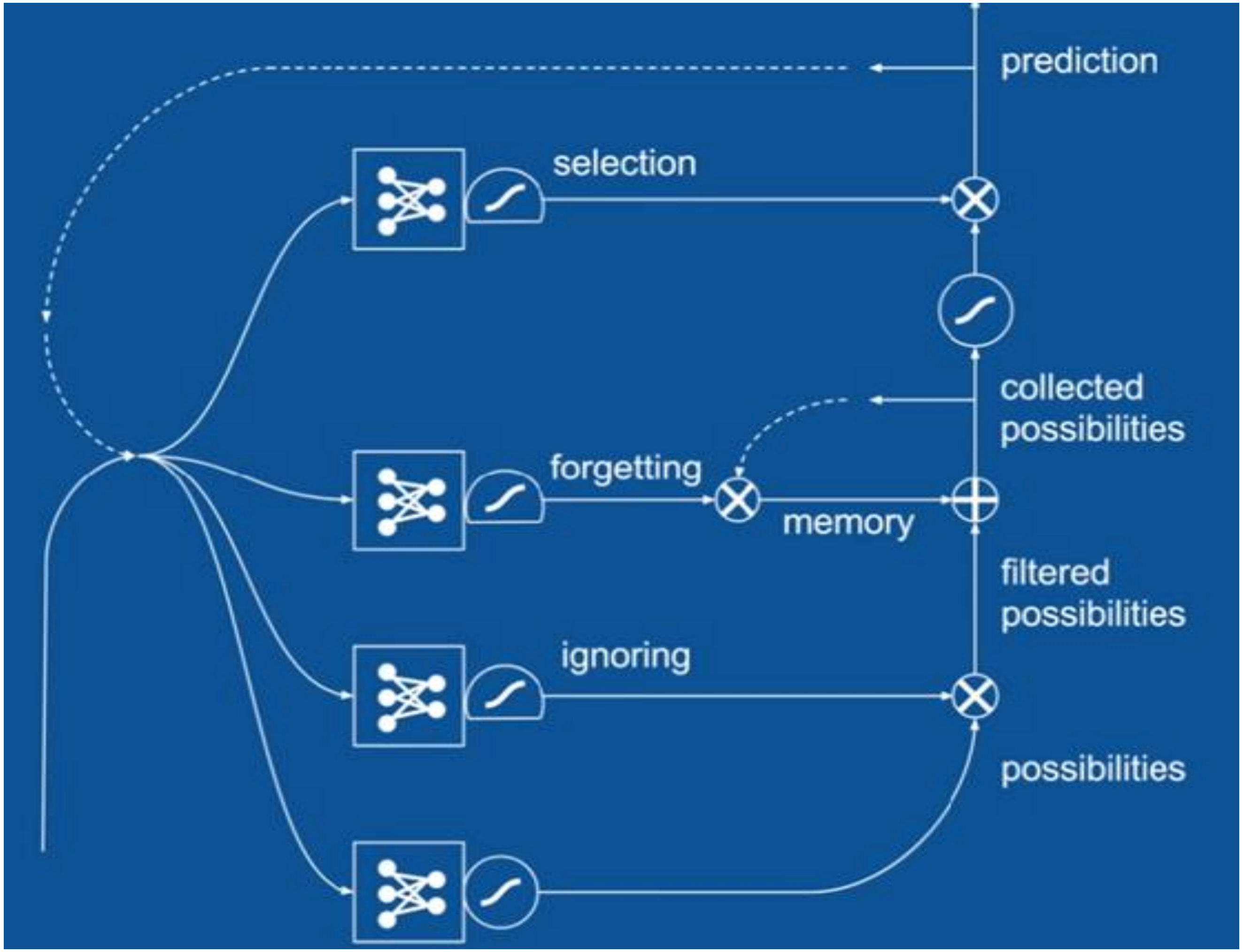



0082KWNMU1L
0082KWNMU2L
0082KWNMU3L
0083KWNMU1L
0083KWNMU2L
0083KWNMU3L
0100KWNMU1L
0100KWNMU2L
0100KWNMU3L
Speed (km/hr)
125
100
75
50
25
02
06
10
14
18
22
Time

Scheme	Statistics (Average)			
	Duration (s)	Waiting Time(s)	Time Loss(s)	Depart Delay(s)
n/a	391.17	8.3	120.73	97.74
1	391.97	8.21	117.36	97.34
2	378.56	6.81	110.13	95.53
3	385.83	9.04	111.58	93.90
4	373.15	8.64	105.16	92.09

2. Further data analysis: traffic prediction by LSTM & BAM-LSTM methods

LSTM Cell


prediction
selection
collected
possibilities
forgetting
memory
filtered
possibilities
ignoring
possibilities

Traditional LSTM with forget gates*

Initial values $c_0 = 0$ and $h_0 = 0$.

The operator $'\mathrm{o}'$ denotes the Hadamard product

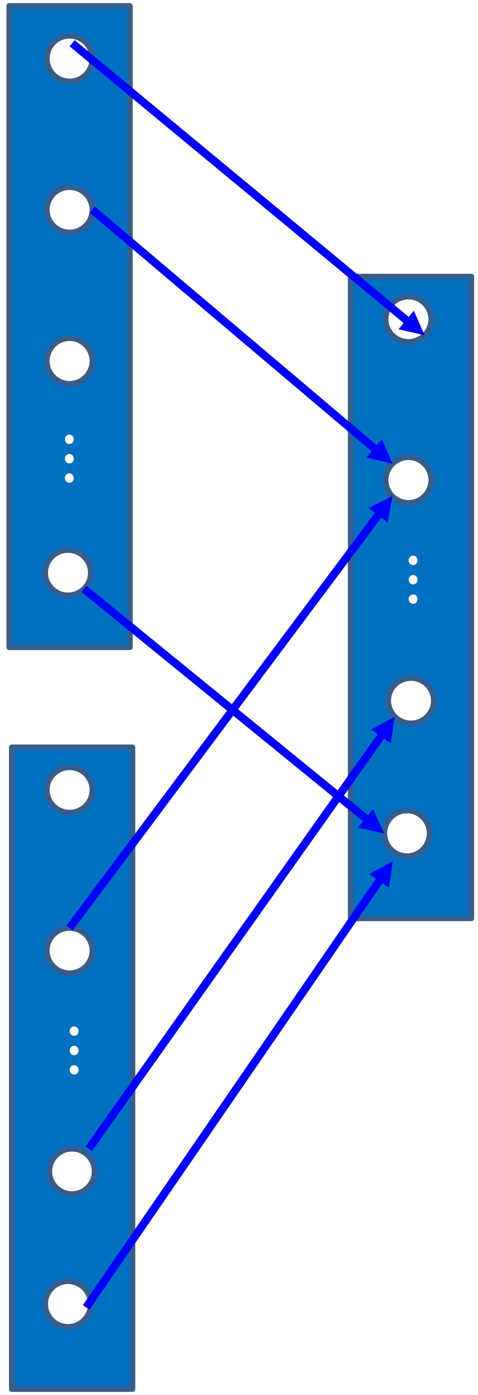
$$f_t = \sigma_g(W_f x_t + U_f h_{t-1} + b_f)$$
$$i_t = \sigma_g(W_i x_t + U_i h_{t-1} + b_i)$$
$$o_t = \sigma_g(W_o x_t + U_o h_{t-1} + b_o)$$
$$h_t = o_t \circ \sigma_h(c_t)$$
$$c_t = f_t \circ c_{t-1} + i_t \circ \sigma_c (W_c x_t + U_c h_{t-1} + b_c)$$

where σ_g: a sigmoid function

σ_c : a hyperbolic function

σ_h : a hyperbolic tangent function

Prediction for yesterday

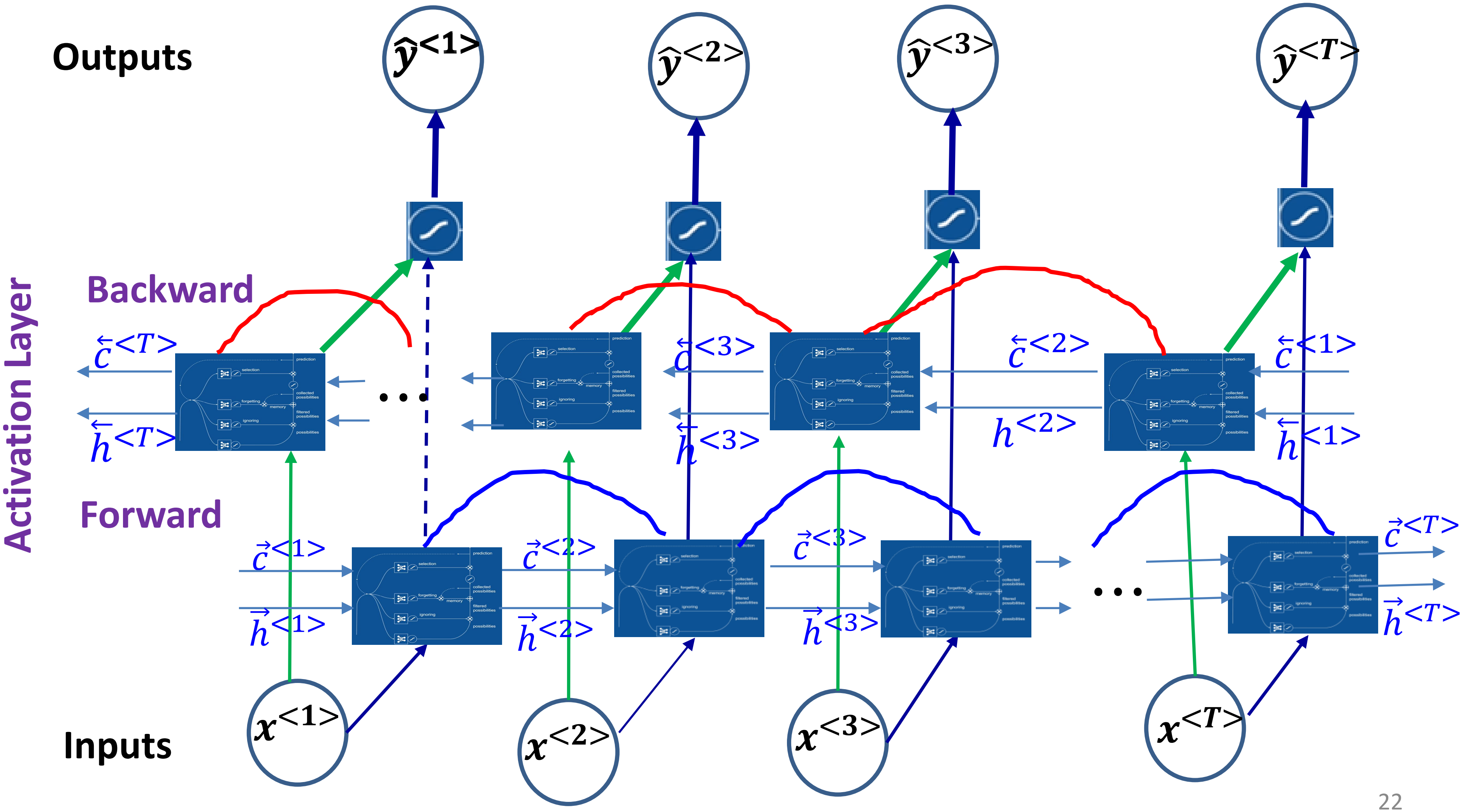


Prediction for today

Traffic flow rate for yesterday

Bidirectional Recurrent Neural Network

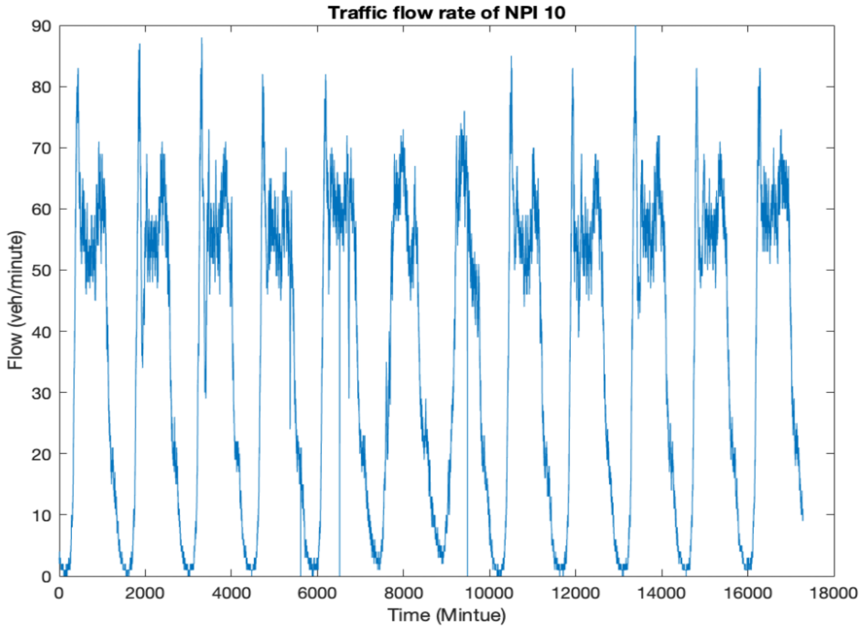
$$\hat{y}^{<t>} = g(W_y[\vec{a}^{<1>}, \overleftarrow{a}^{<1>}] + b_y)$$

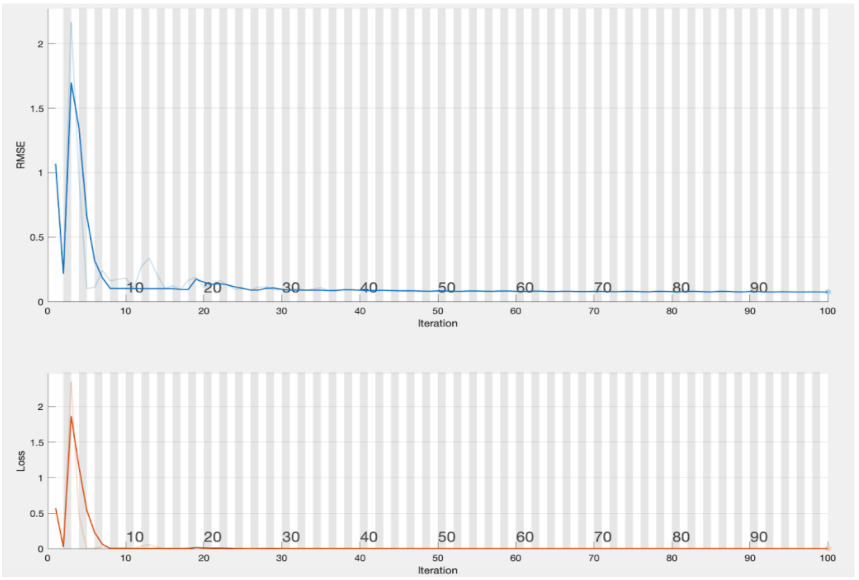


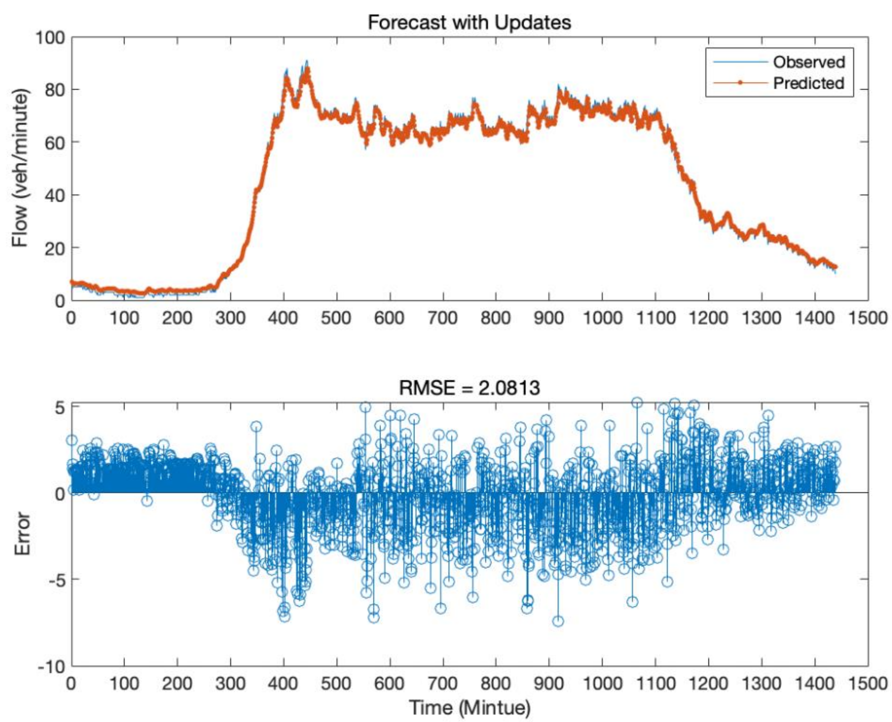
Hyperparameters for BRNN

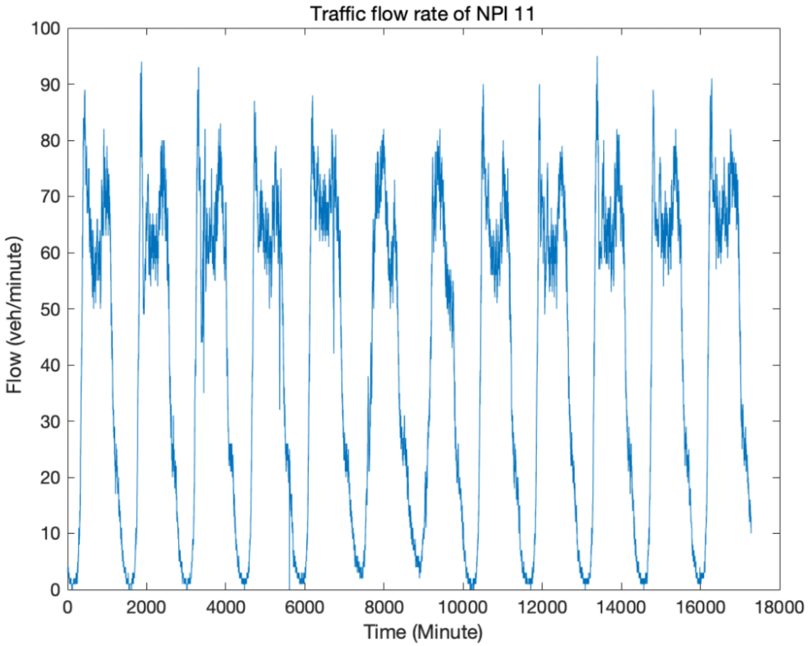
- Input size = 144000
- Sequence length = 1440
- Number of layers = 2
- Hidden size = 50
- Number of classes = 2
- Learning rate = 0.005
- Batch size = 120
- Number of epochs = 100

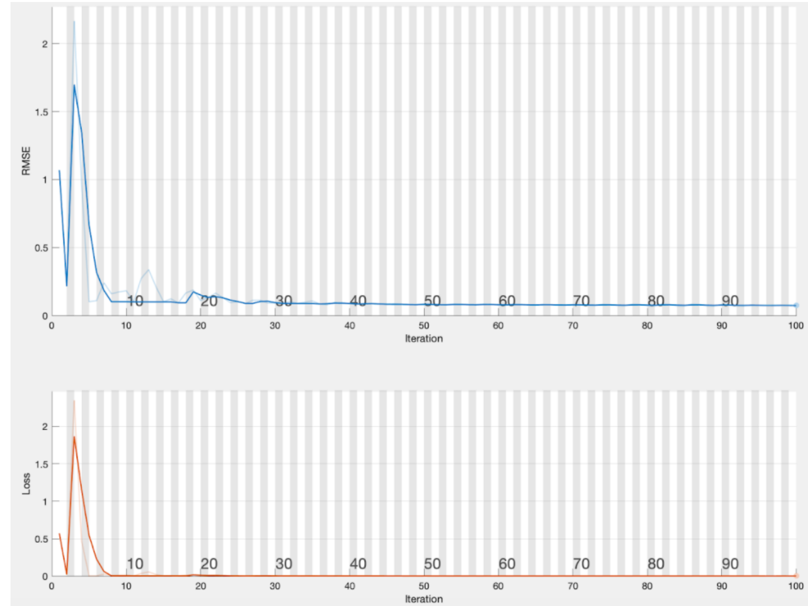
Traffic Flow Rate
Veh/minute

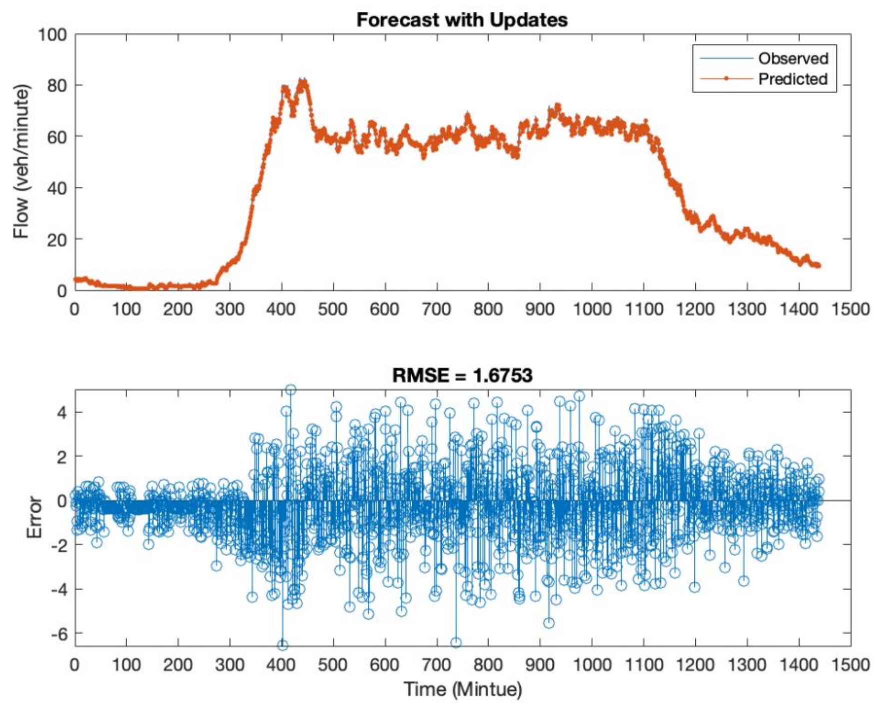

Traffic flow rate of NPI 10
Flow (veh/minute)
Time (Mintue)


RMSE
Loss
Iteration

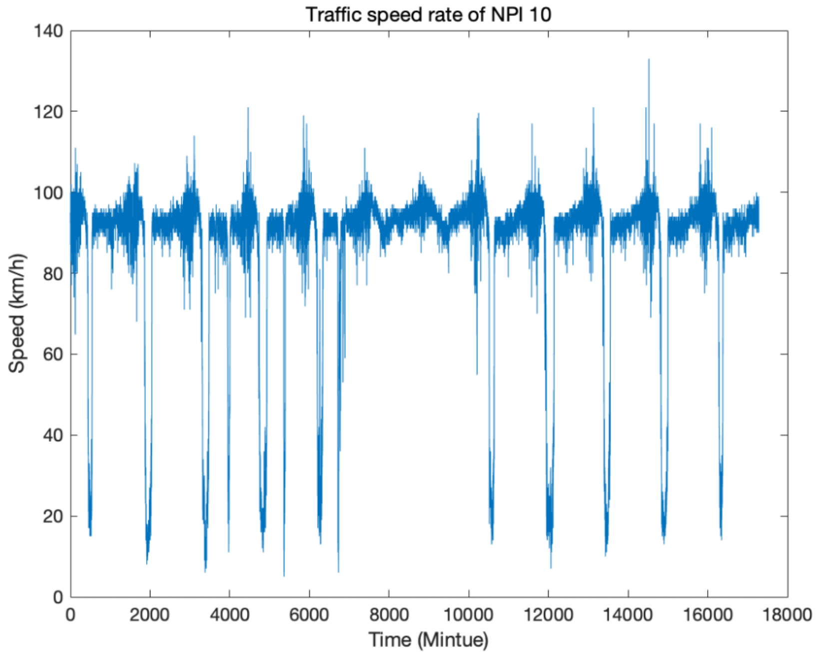

Forecast with Updates
Observed
Predicted
Flow (veh/minute)
RMSE = 2.0813
Error
Time (Mintue)

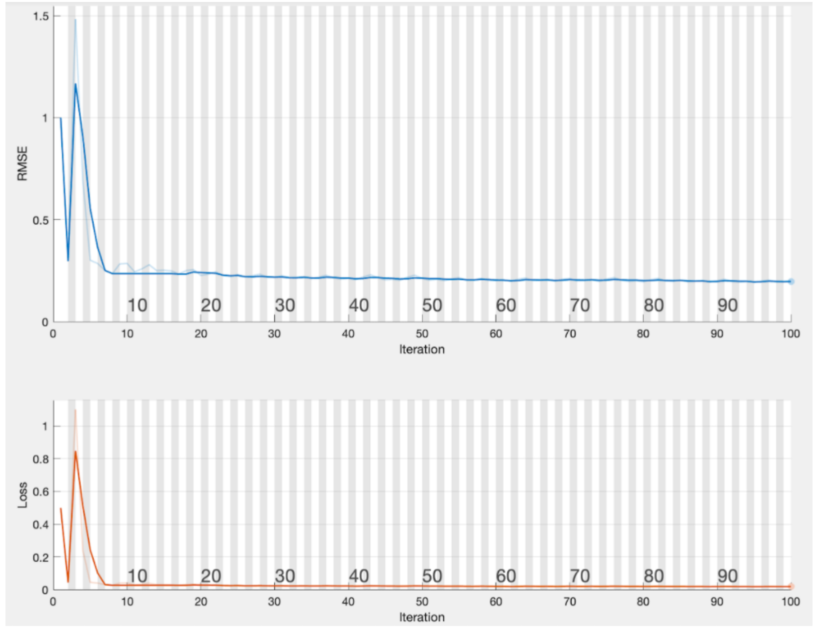

Traffic flow rate of NPI 11
Flow (veh/minute)
Time (Minute)

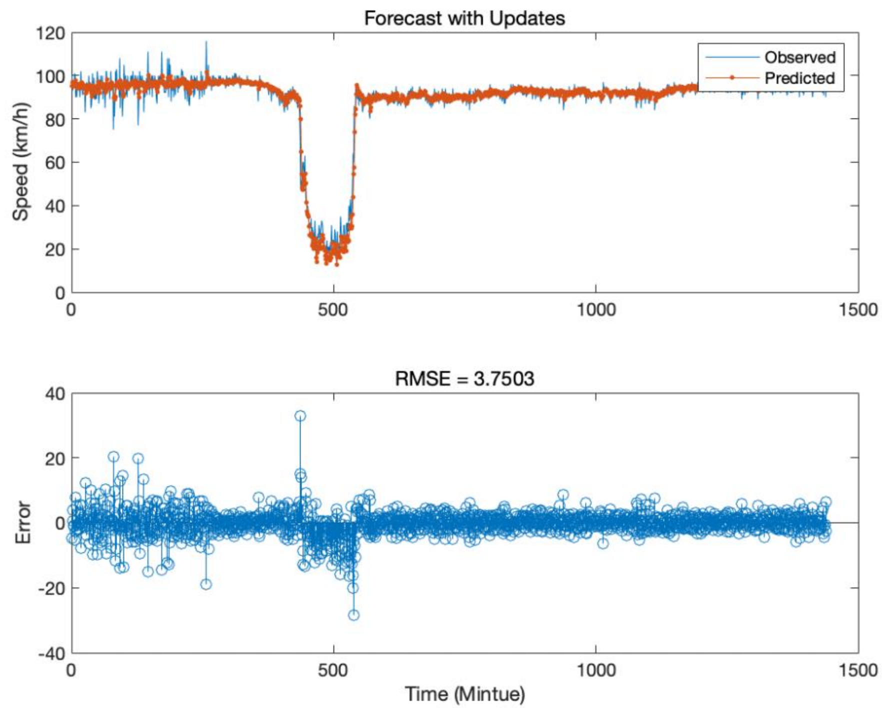

RMSE
Iteration
Loss
Iteration

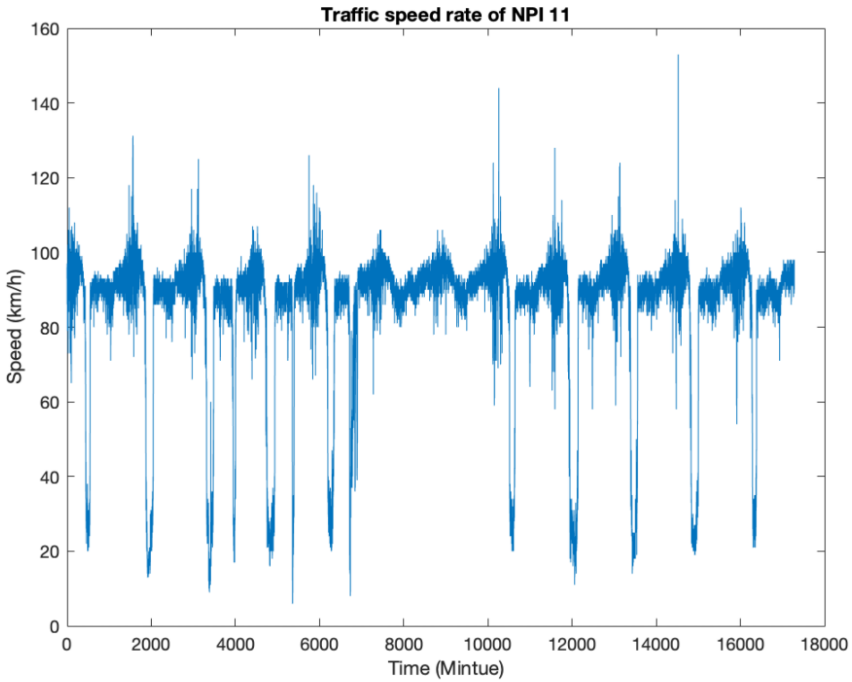

Forecast with Updates
Observed
Predicted
Flow (veh/minute)
RMSE = 1.6753
Error
Time (Mintue)

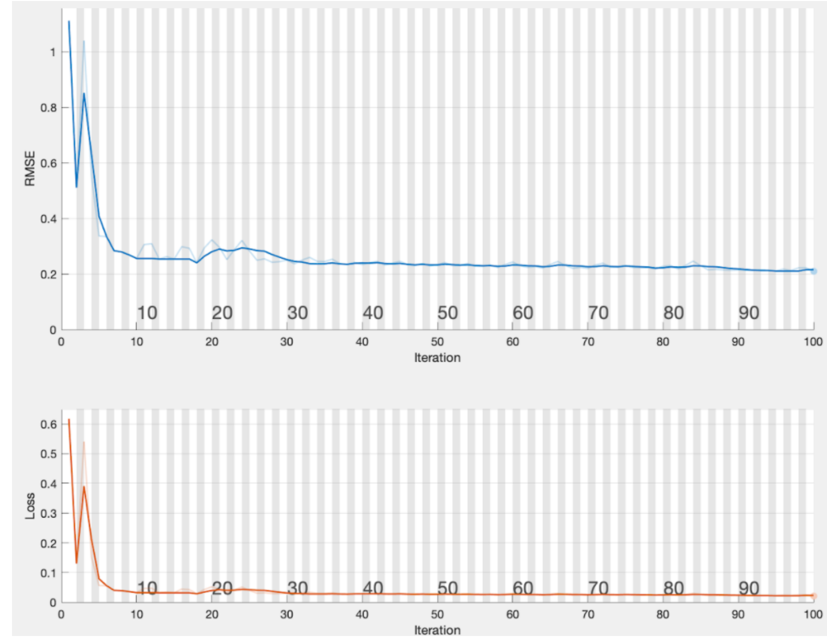
Traffic Speed
km/hr

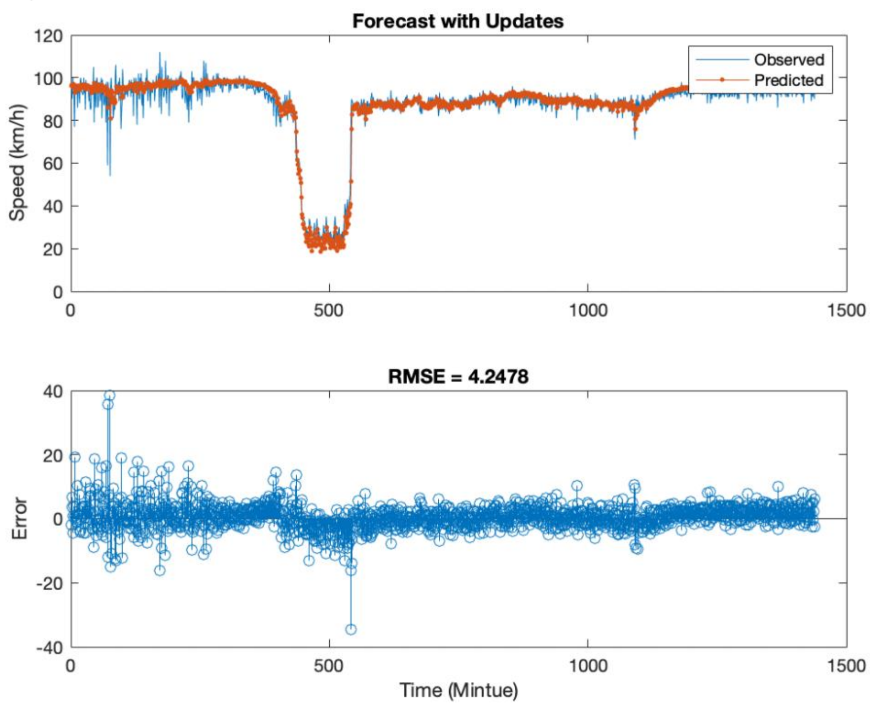

Traffic speed rate of NPI 10
Speed (km/h)
Time (Mintue)


RMSE
Iteration
Loss
Iteration

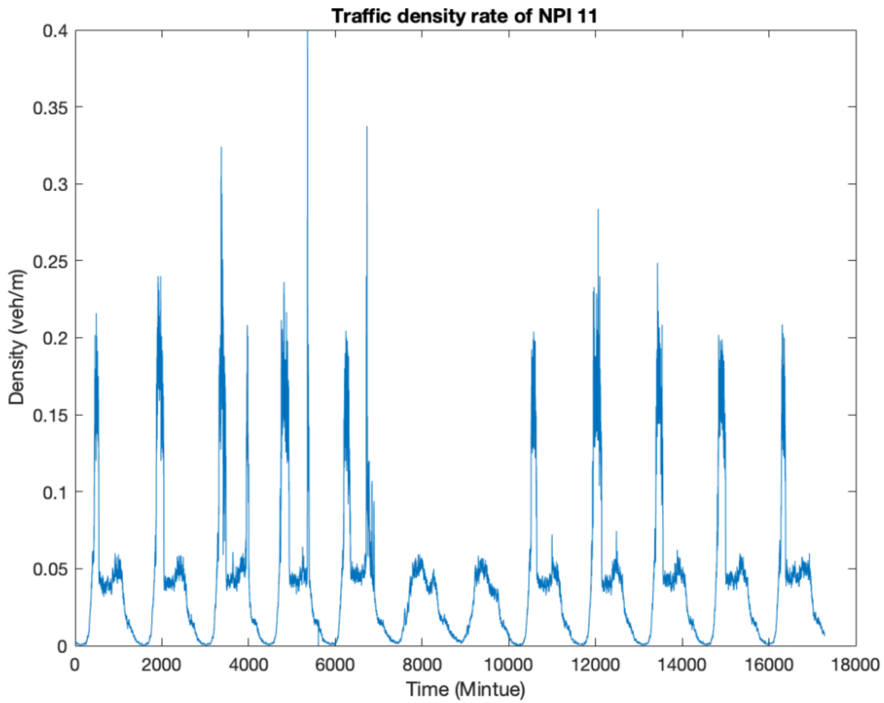

Forecast with Updates
Speed (km/h)
Observed
Predicted
RMSE = 3.7503
Error
Time (Mintue)

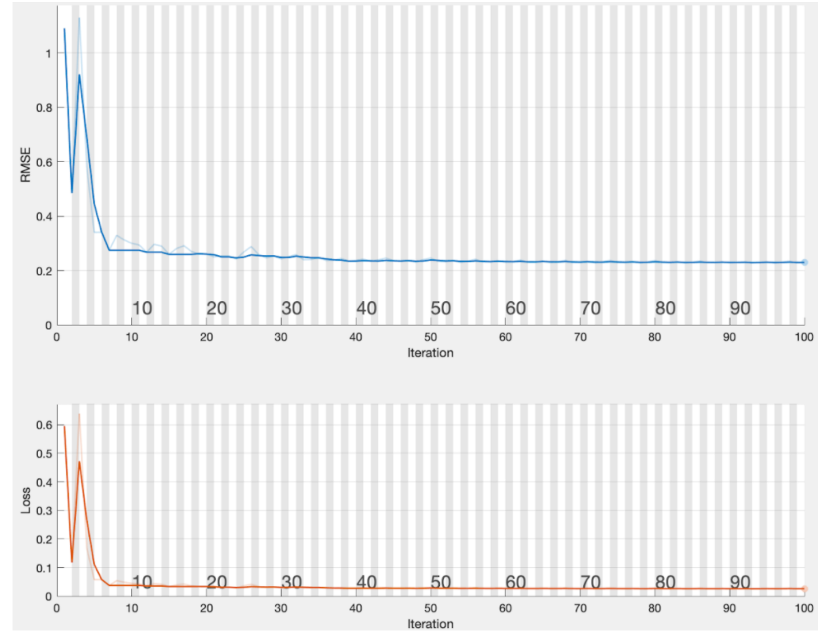

Traffic speed rate of NPI 11
Speed (km/h)
Time (Mintue)

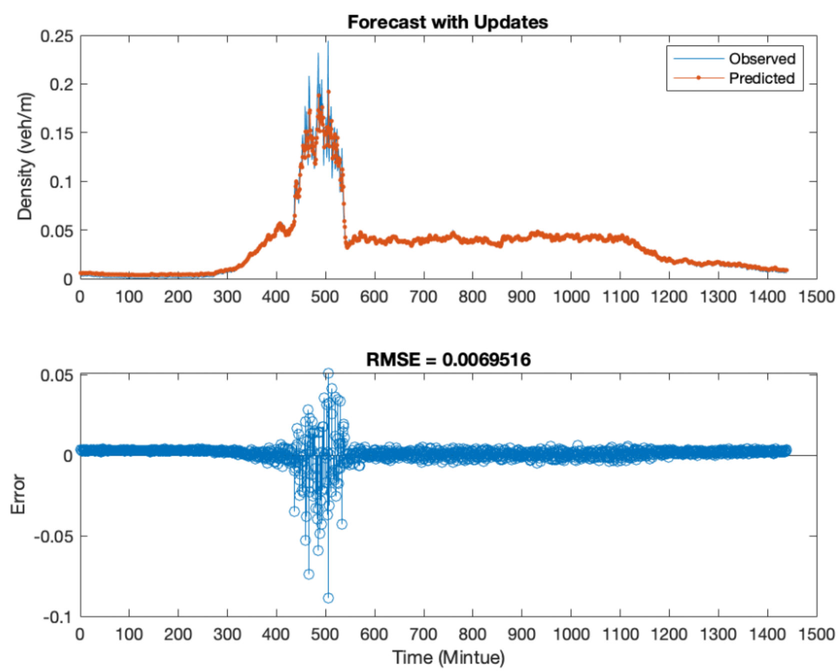

RMSE
Loss
Iteration


Forecast with Updates
Observed
Predicted
Speed (km/h)
RMSE = 4.2478
Error
Time (Mintue)

Traffic Density
Veh/meter


Traffic density rate of NPI 11
Density (veh/m)
Time (Mintue)

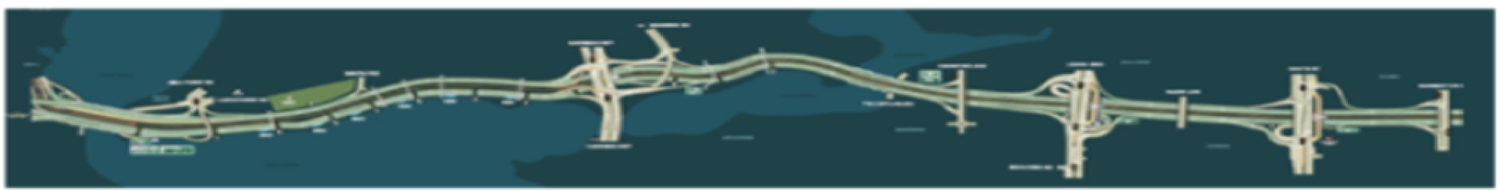

RMSE
Iteration
Loss
Iteration

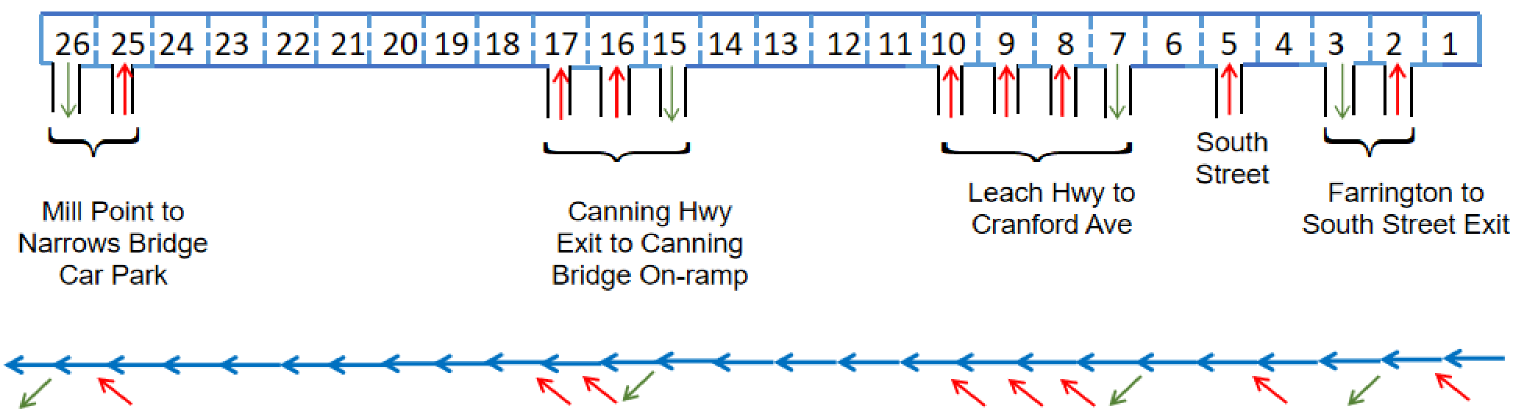

Forecast with Updates
Observed
Predicted
Density (veh/m)
RMSE = 0.0069516
Error
Time (Mintue)

3 Optimization of freeway traffic flow via ramp metering

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

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





Optimization Model

Objective function: $$D_t = \sum_{l=t}^{t+N_p-1} [\sum_{i=1}^{I} (\rho_{i,l}\Delta x_i \Delta t - \frac{f_{i,l}\Delta x_i \Delta t}{v_i}) + \sum_{j=1}^{J} q_{j,l}\Delta t].$$

s.t. $$\rho^{\varepsilon}_{i,t+1} = \rho^{\varepsilon}_{i,t} + \frac{\Delta t}{\Delta x_i} \times (f^{\varepsilon}_{i-1,t}(\rho^{\varepsilon}_{i-1,t}) - f^{\varepsilon}_{i,t}(\rho^{\varepsilon}_{i,t}) + r_{i,t} - s_{i,t}), \forall i,t,$$

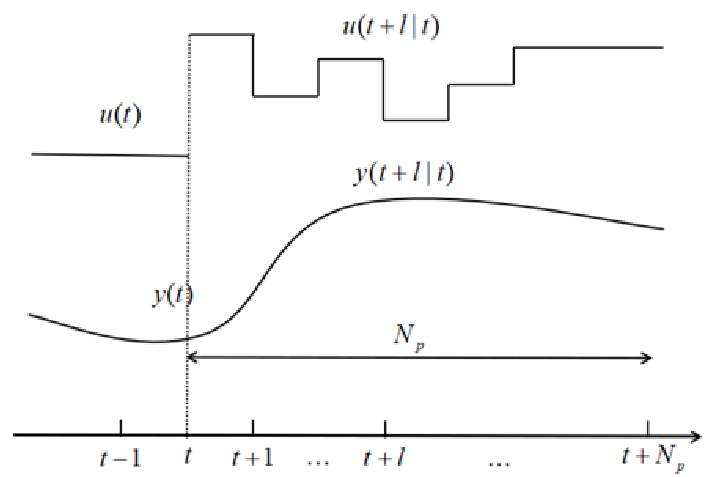
$$q_{j,t+1} = q_{j,t} + (d_{j,t} - r_{j,t})\Delta t, \forall j,t,$$

$$0 \leq \rho^{\varepsilon}_{i,t} \leq \rho_{max,i}, \forall i,t,$$

$$0 \leq q_{j,t} \leq q_{max}, \forall j,t.$$

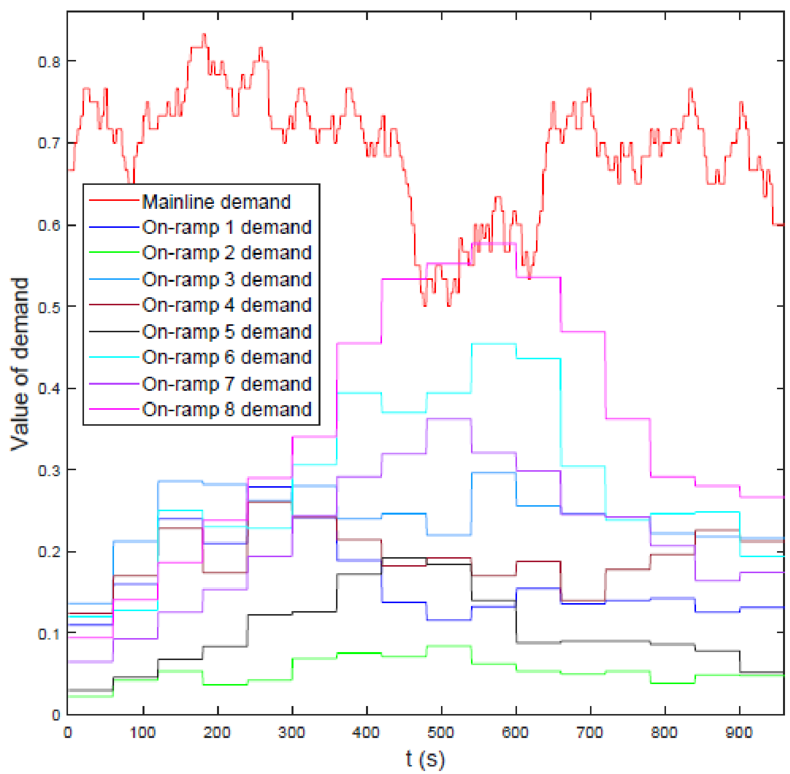
$$0 \leq r_{j,t} \leq r_{max,j}, \forall j,t.$$

Model Predictive Control (MPC)

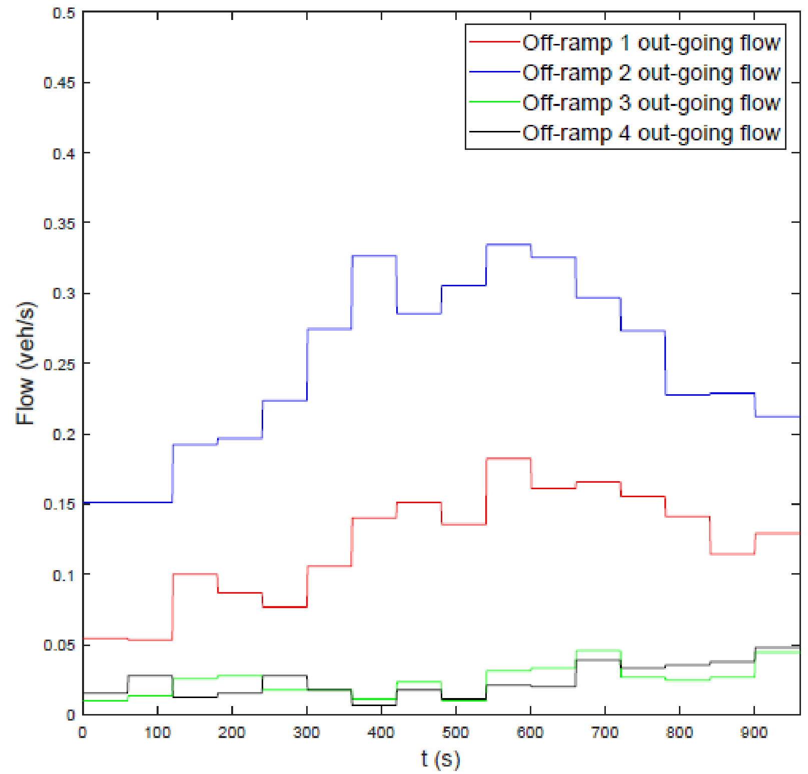


$$f_{i,t} = \min\{v_i\rho_{i,t}, C_i, C_{i+1}, w_{i+1}(\rho_{max,i+1} - \rho_{i+1,t}), \forall i,t,$$

Demand flows and out-going flows

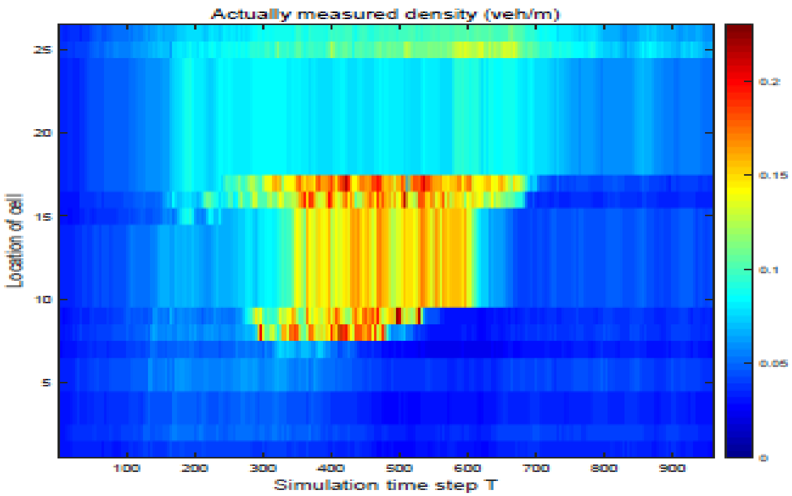


(a) Mainline demand and on-ramp demands

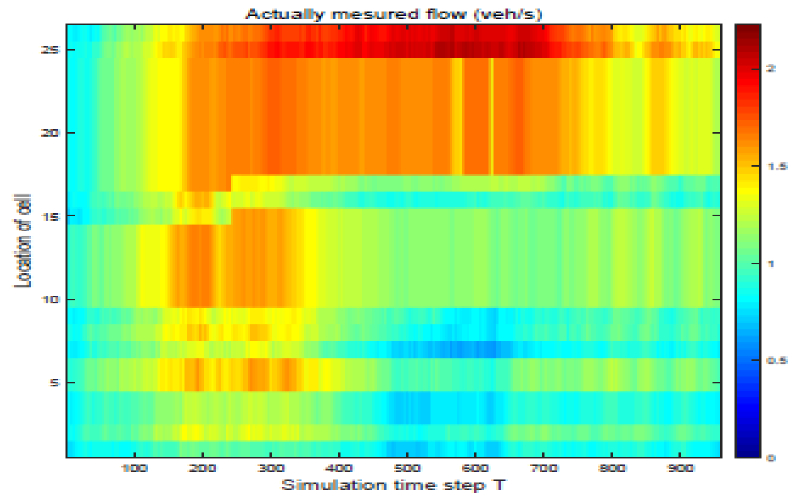


(b) Out-going flow

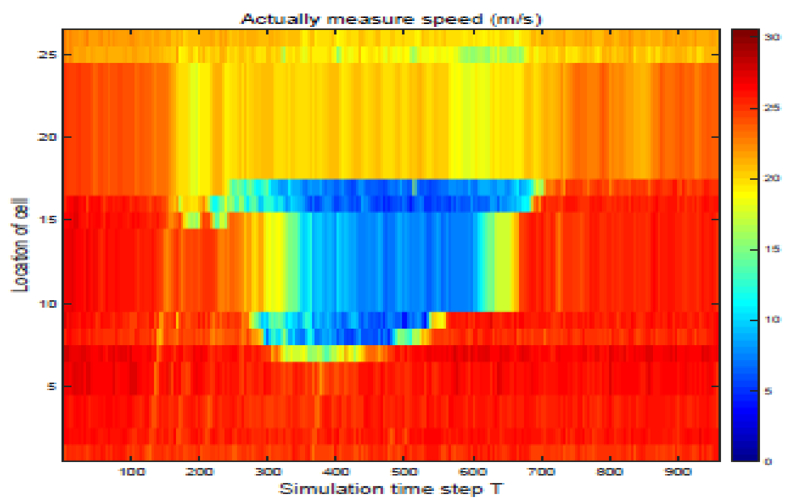
Density, speed and flow from actual measured data 11/06/2018



(a) Density

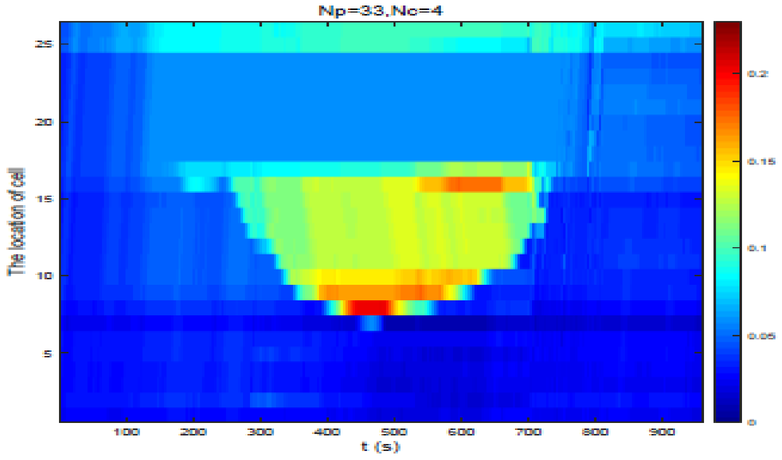


(b) Flow

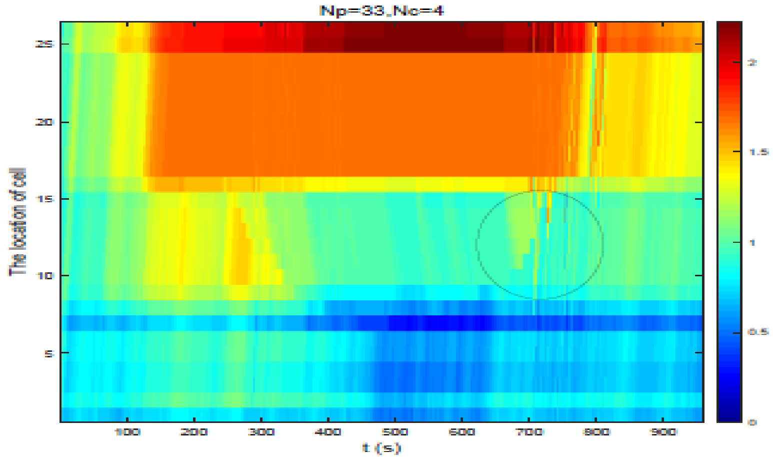


(c) Speed

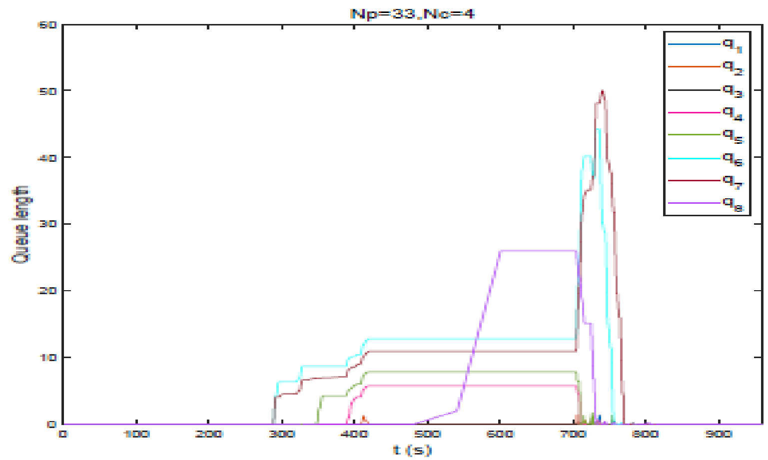
Numerical results for inequality relaxation for Np=33,Nc=4



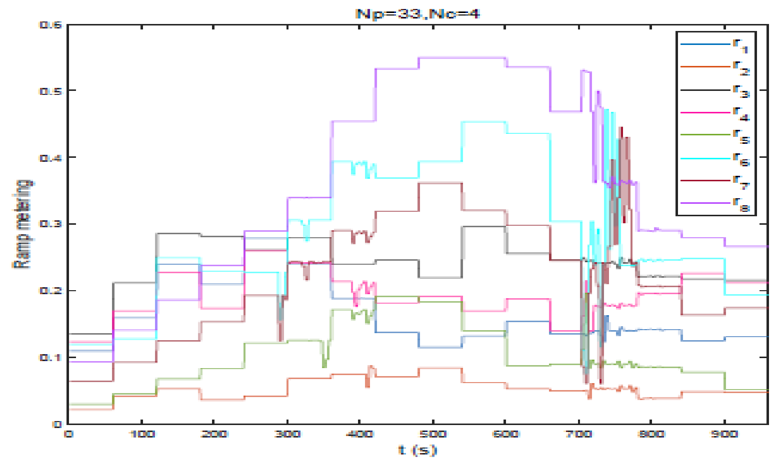
(a) Density



(b) Flow

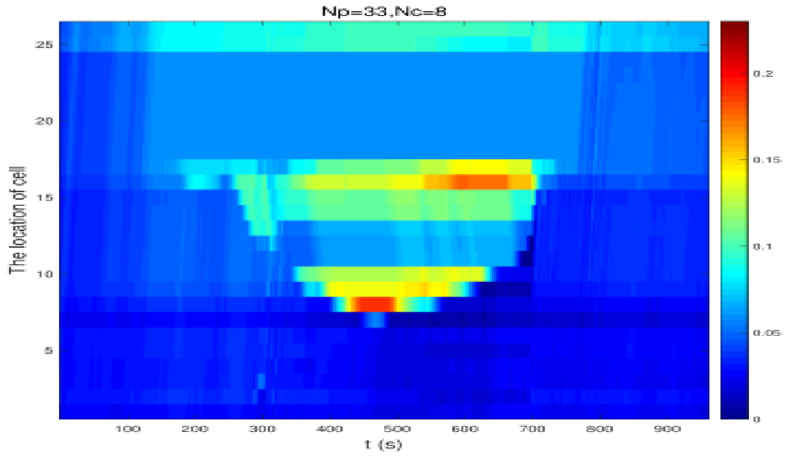


(c) Queue length

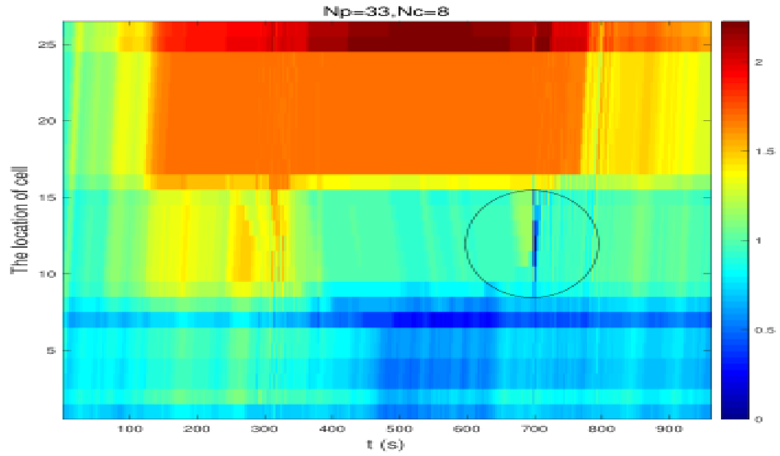


(d) Ramp metering

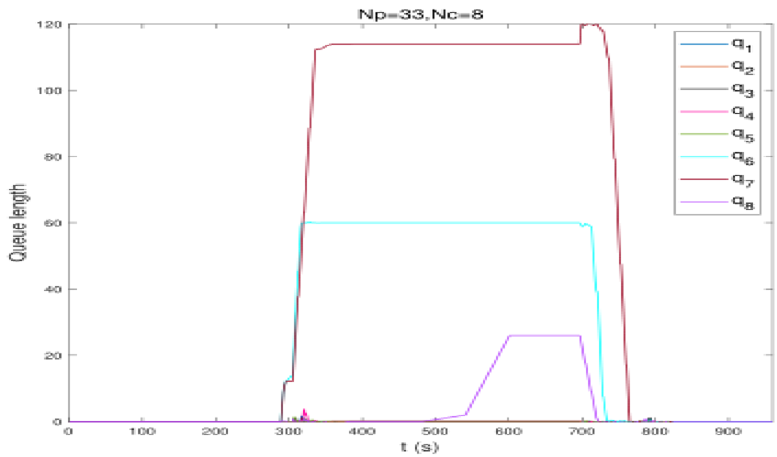
Numerical results for inequality relaxation for Np=33,Nc=8



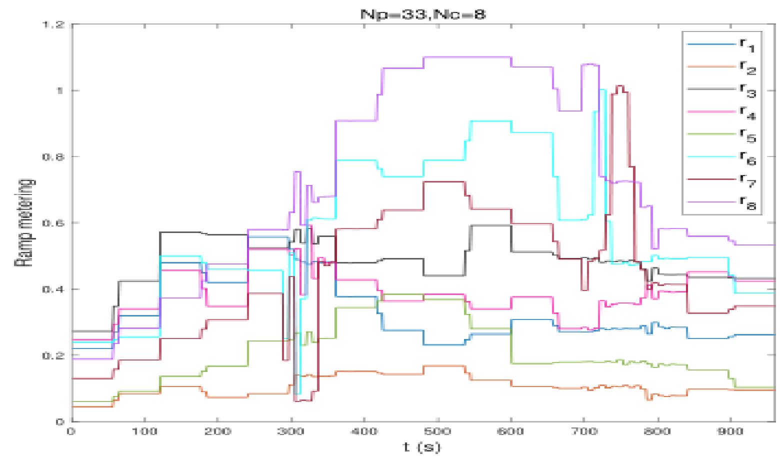
(a) Density



(b) Flow

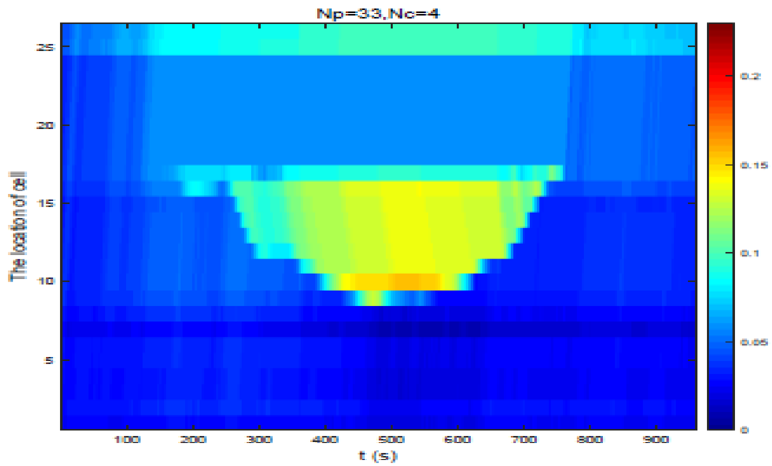


(c) Queue length

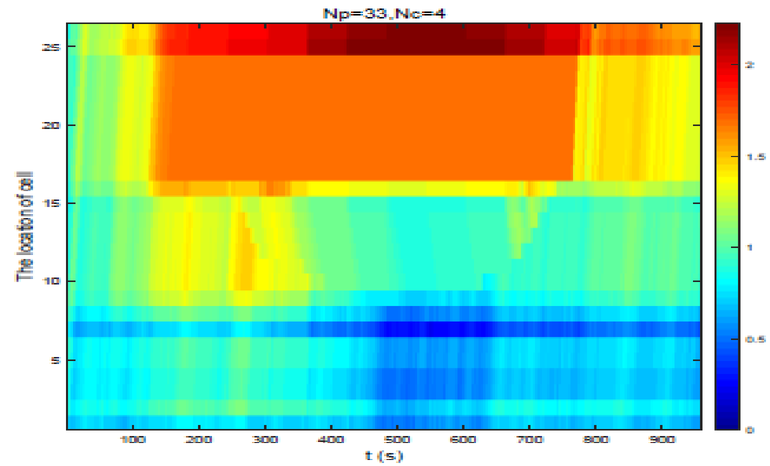


(d) Ramp metering

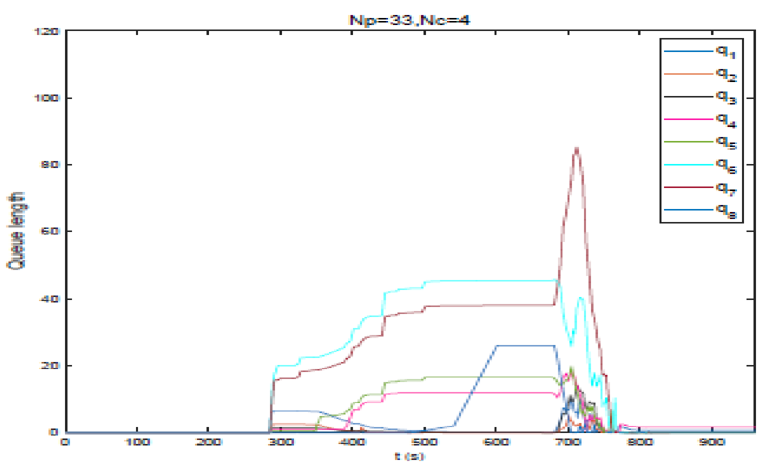
Numerical results for approximated model for Np=33,Nc=4



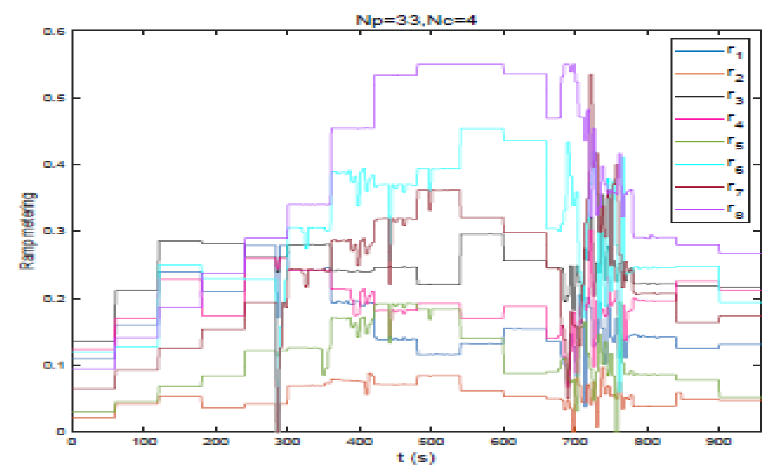
(a) Density



(b) Flow

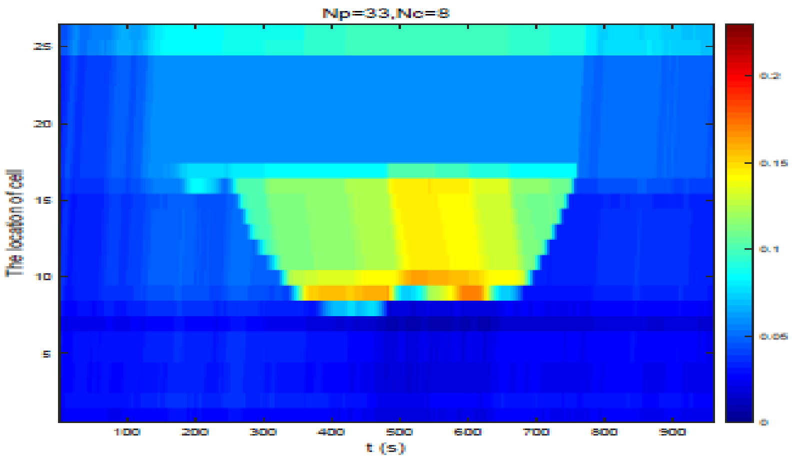


(c) Queue length

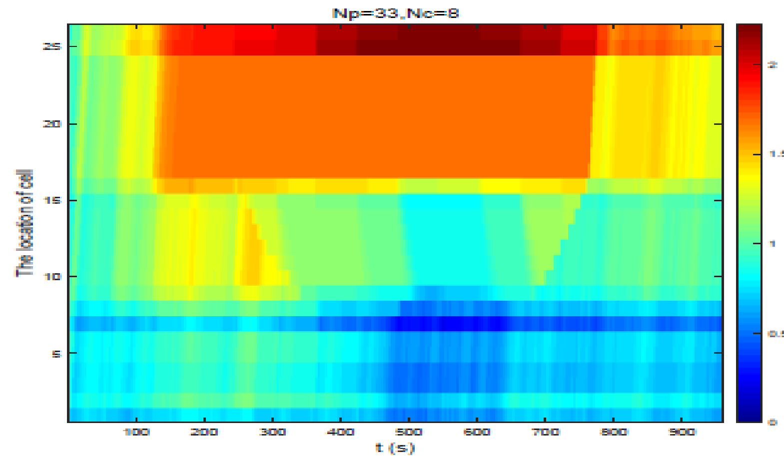


(d) Ramp metering

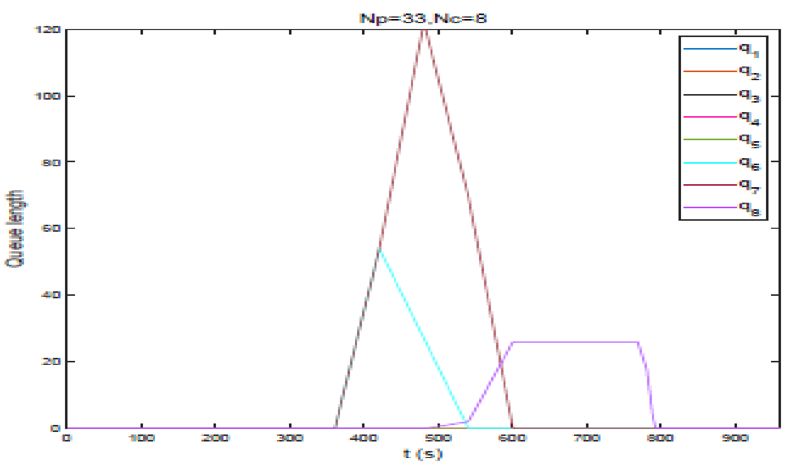
Numerical results for approximated model for Np=33,Nc=8



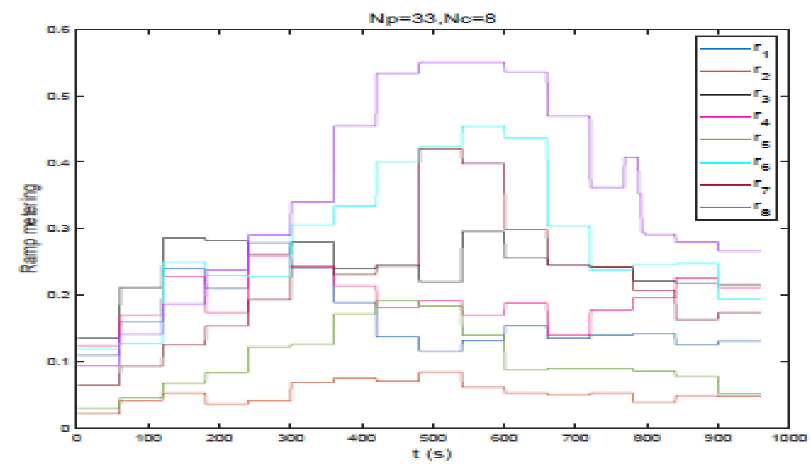
(a) Density



(b) Flow



(c) Queue length



(d) Ramp metering

Comparison of total delay and ramp delay

Name of model	Total delay	Ramp delay
No control	1270.3164h	0h
Inequality relaxation model with $Nc = 4$	781.3429h	87.3461h
Inequality relaxation model with $Nc = 8$	772.7768h	325.4634h
Approximated model with $Nc = 4$	765.9473h	199.2427h
Approximated model with $Nc = 8$	761.2329h	105.0768h

ACKNOWLEDGEMENTS

The project is funded by the Australian Research Council, Main Roads WA, and Roads and Maritime Services NSW.

Acknowledgement is made to the Australian Research Council, Main Roads WA, Roads and Maritime Services NSW, and the Australia's Sustainable Built Environment National Research Centre (SBEnrc) for their support.

THANK YOU

For Your Attention