Microsimulation of Traffic flow on the Kwinana Freeway with Ramp Metering and Variable Speed Limit

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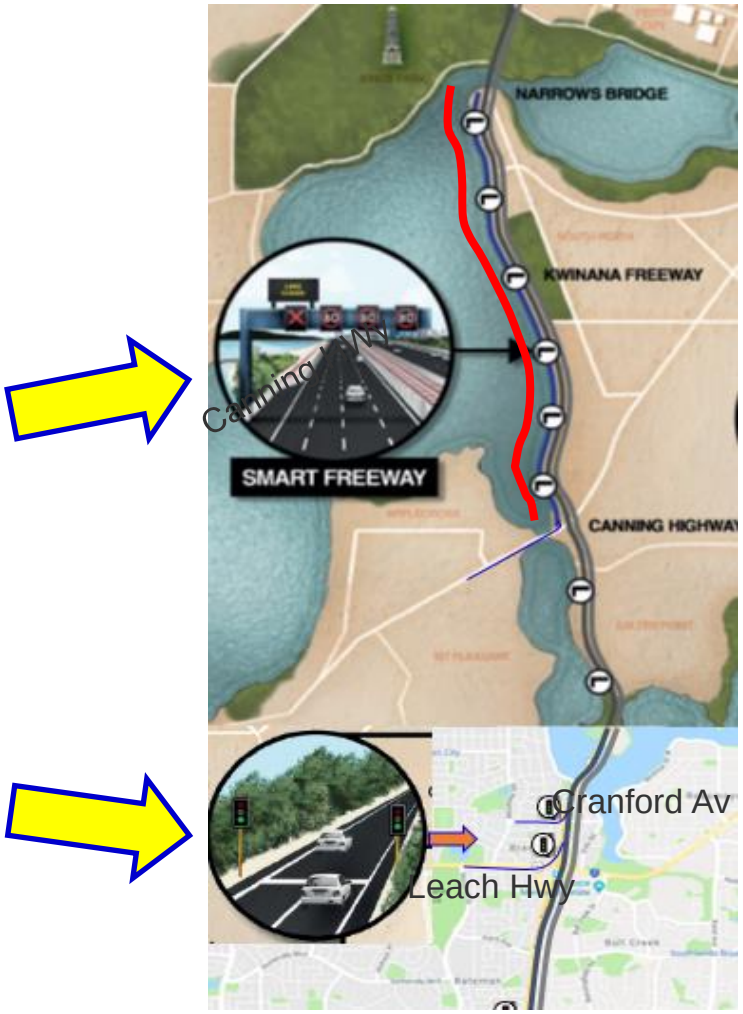
Smart Freeway Kwinana Northbound

Smart freeways - traffic modelling and control

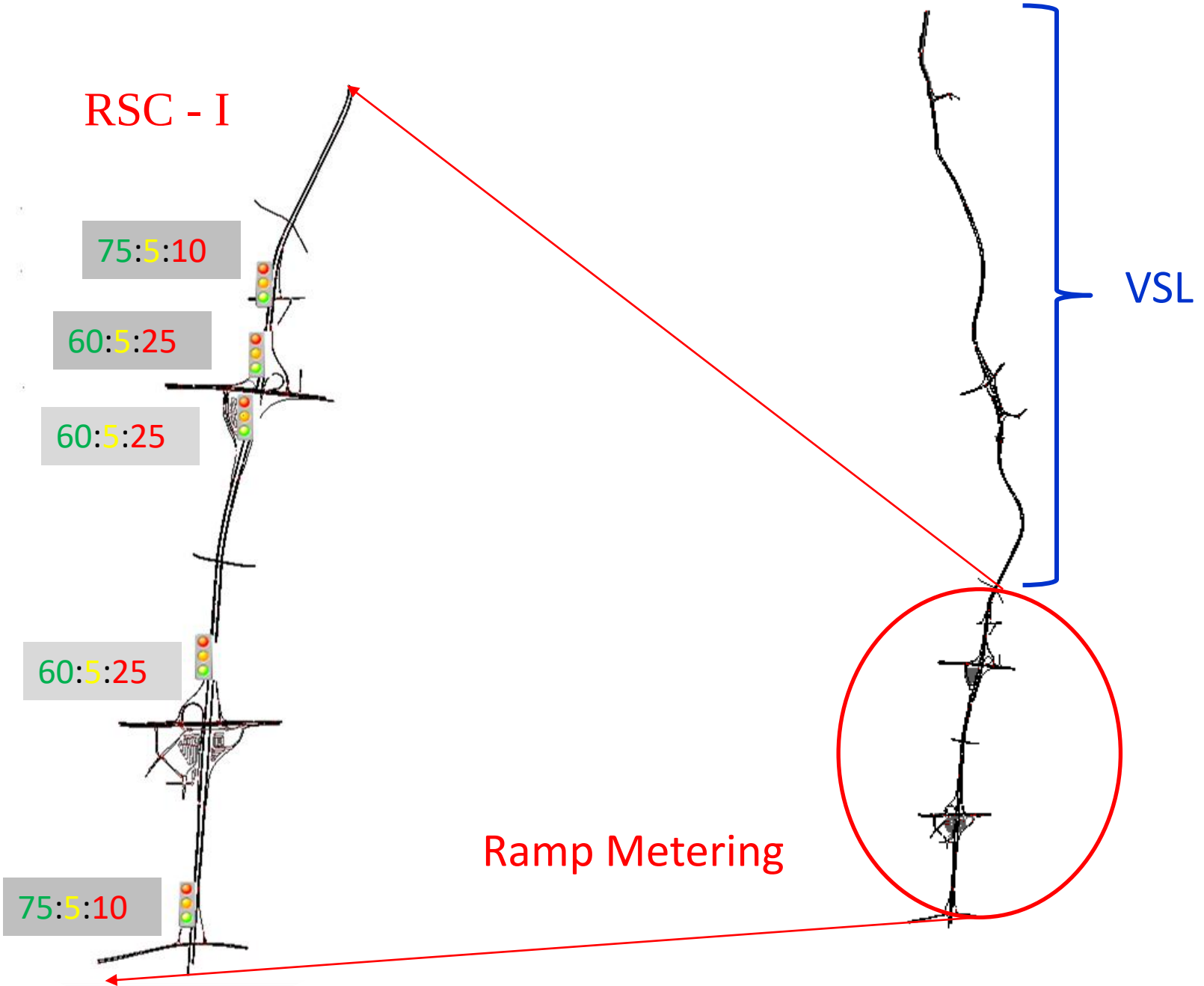
To improve traffic flows on highways/freeways to meet the future demand,
smart highways/freeways technologies have been developed in many countries

eg. A smart freeways – Kwinana northbound

- Electric device & CCTV
- Coordinated Signals at on-ramps
- Variable Speed Limits
- Real Time Traffic Information
- Emergency Stopping Bays in place every 500m-700m



from Main Roads & Google Maps


RSC - I
75:5:10
60:5:25
60:5:25
60:5:25
75:5:10
VSL
Ramp Metering

Typical Research Problems in Smart Highways/freeways Study

- Construct robust models for **traffic flows** (Microscopic/Macroscopic/Mesoscpic)
  - on freeways
  - with lane changes
  - with merging of on-ramp traffic
- Study **optimization strategies**
  - max throughput
  - min occurrence of recurrent congestion
  - min impact of non-recurrent congestion
  - max operation safety
  - min travel time … etc

subject to **constraints**

- minimum entry rate at on-ramps
- maximum speed limit
- minimum waiting time …etc

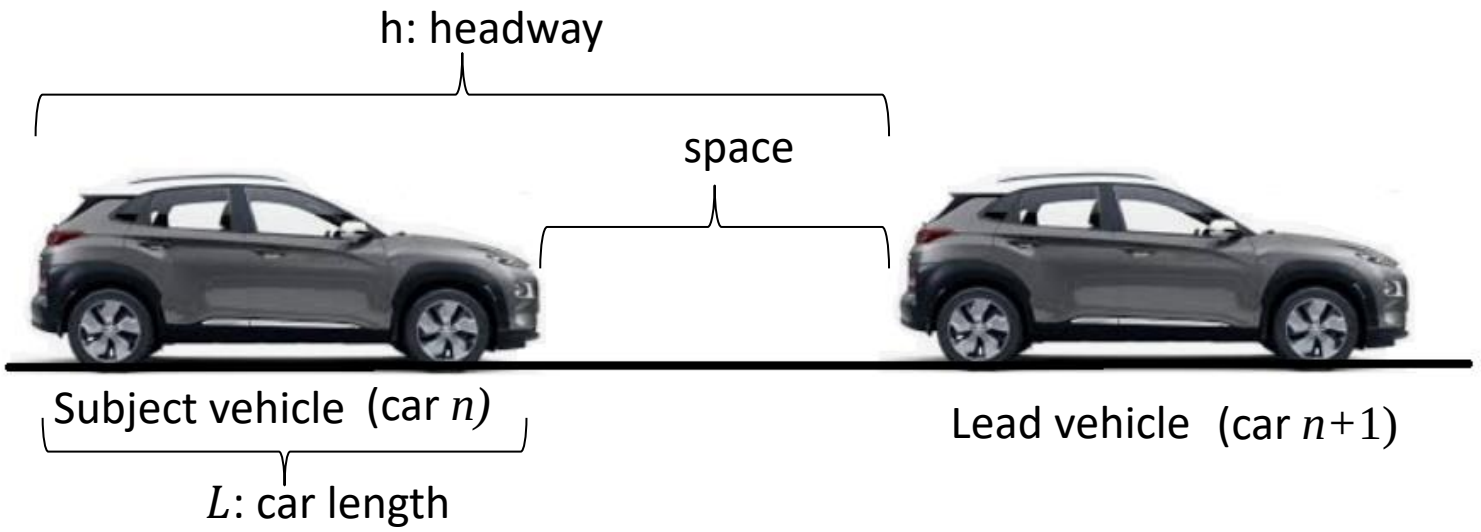
Remarks

For the success of smart highways, it is important to model traffic flow accurately

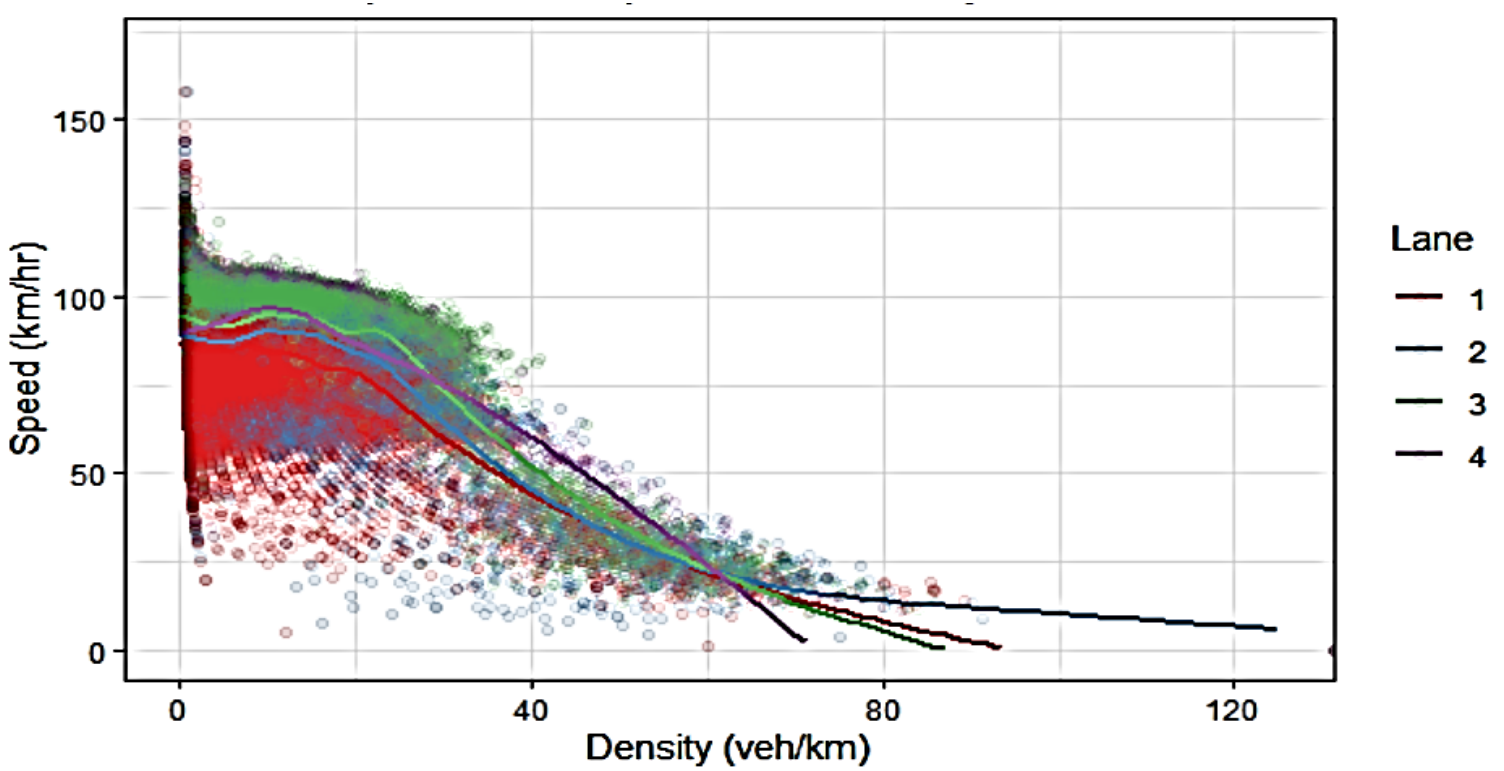
Microscopic Car-following Model

Let $x_n(t)$ be position of car n at time t

$$\ddot{x}_n(t) = \underbrace{\frac{1}{\tau}\left(\dot{x}_{n+1}(t) - \dot{x}_n(t)\right)}_{\text{Reaction term}} + \underbrace{\frac{1}{T}\left(V(h_n(t)) - \dot{x}_n(t)\right)}_{\text{Relaxation term}},$$



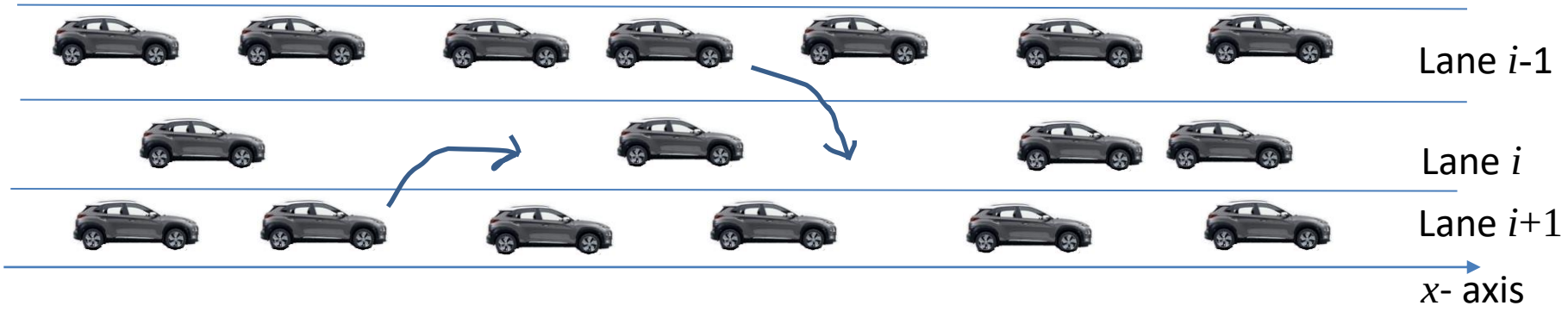
Fundamental Diagram (FD)



1st order Lane-Changing Macroscopic model

Lane change from lane i to its neighboring lane j, $(j = i-1 \text{ or } i+1)$

when
$$v_j > (1+\alpha)v_i \quad \text{(a)}$$
$$h(\rho_j) > h_{min} + v_i t \quad \text{(b)}$$



$$\partial_t(\rho_i) + \partial_x(\rho_i V_i)$$
$$= \frac{p}{\tau_L}\left[-\underbrace{\left(\delta_{i,i-1} + \delta_{i,i+1}\right)}_{\text{Loss terms}}\rho_i + \overbrace{\left(\rho_{i-1}\delta_{i-1,i} + \rho_{i+1}\delta_{i+1,i}\right)}^{\text{Gain terms}}\right],$$

$$V_i = V(\rho_i) = \begin{cases} VSL & \rho_i \to 0 \\ 0 & \rho_i \to \rho_{max} \end{cases} \qquad \delta_{i,j} = \begin{cases} 1 & if\ (a),(b) are\ met \\ 0 & otherwise \end{cases}$$

3-lane Fwy section with on-/off- ramp

$$\partial_t(\rho_0) + \partial_x(\rho_0 V_0) = \frac{1}{\tau_L}(-\delta_{0,1}\rho_0) \Leftarrow \text{on-Ramp}$$

$$\partial_t(\rho_0) + \partial_x(\rho_0 V_0) = \frac{1}{\tau_L}(\delta_{1,0}\rho_1) \Leftarrow \text{off-Ramp}$$

$$\partial_t(\rho_1) + \partial_x(\rho_1 V_1) = \frac{p}{\tau_L}(-(\delta_{1,2} + \delta_{1,0})\rho_1 + \delta_{0,1}\rho_0 + \delta_{2,1}\rho_2)$$

$$\partial_t(\rho_2) + \partial_x(\rho_2 V_2) = \frac{p}{\tau_L}\left(\delta_{1,2}\rho_1 - (\delta_{2,1}+\delta_{2,3})\rho_2 + \delta_{3,2}\rho_3\right)$$

$$\partial_t(\rho_3) + \partial_x(\rho_3 V_3) = \frac{p}{\tau_L}\left(\delta_{2,3}\rho_2 - \delta_{3,2}\rho_3\right)$$

n-lane Feeway with on-/off- ramp

$$\partial_t(\rho_0) + \partial_x(\rho_0 V_0) = \frac{1}{\tau_L}(-\delta_{0,1}\rho_0) \Leftarrow \text{on-Ramp}$$

$$\partial_t(\rho_0) + \partial_x(\rho_0 V_0) = \frac{1}{\tau_L}(\delta_{1,0}\rho_1) \Leftarrow \text{off-Ramp}$$

$$\partial_t(\rho_1) + \partial_x(\rho_1 V_1) = \frac{p}{\tau_L}(-(\delta_{1,2} + \delta_{1,0})\rho_1 + \delta_{0,1}\rho_0 + \delta_{2,1}\rho_2)$$

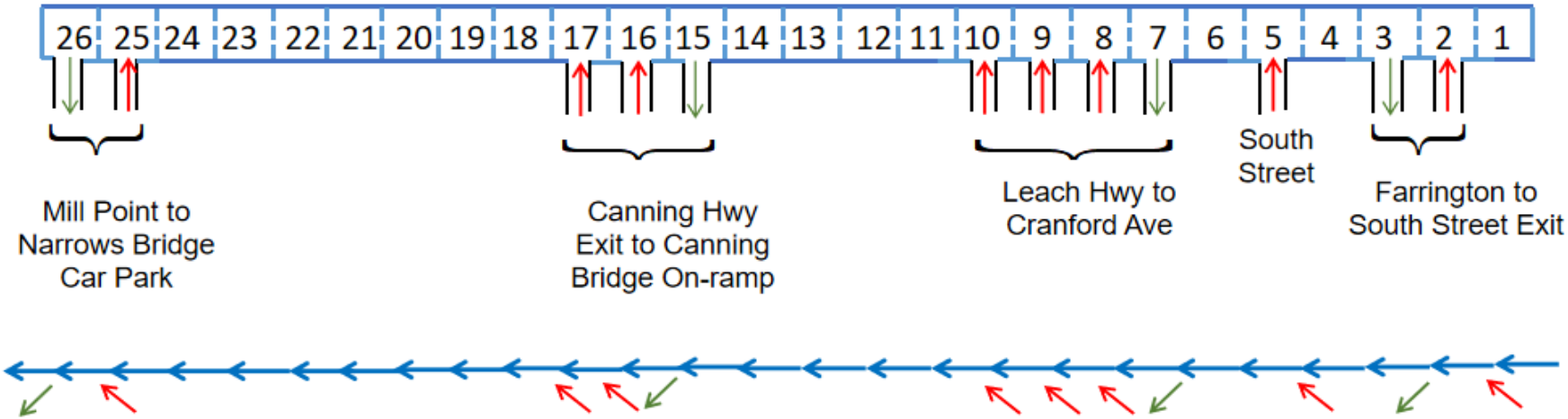
$$\partial_t(\rho_2) + \partial_x(\rho_2 V_2) = \frac{p}{\tau_L}\left(\delta_{1,2}\rho_1 - (\delta_{2,1}+\delta_{2,3})\rho_2 + \delta_{3,2}\rho_3\right)$$

$$\vdots$$

$$\partial_t(\rho_{n-1}) + \partial_x(\rho_{n-1} V_{n-1})$$
$$= \frac{p}{\tau_L}\left(\delta_{n-2,n-1}\rho_{n-2} - (\delta_{n-1,n-2}+\delta_{n-1,n})\rho_{n-1} + \delta_{n,n-1}\rho_n\right)$$

$$\partial_t(\rho_n) + \partial_x(\rho_n V_n) = \frac{p}{\tau_L}\left(\delta_{n-1,n}\rho_{n-1} - \delta_{n,n-1}\rho_n\right)$$

Computation Region



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

Optimization Model

Objective function:

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

s.t.

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

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

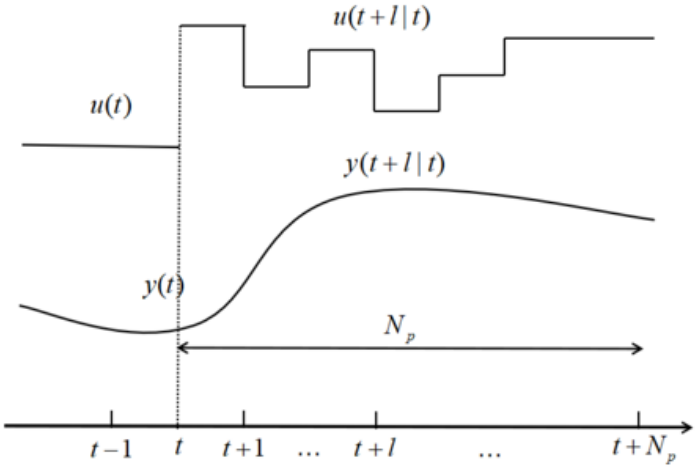
$$q_{j,t+1} = q_{j,t} + (d_{j,t} - r_{j,t})\Delta t,$$

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

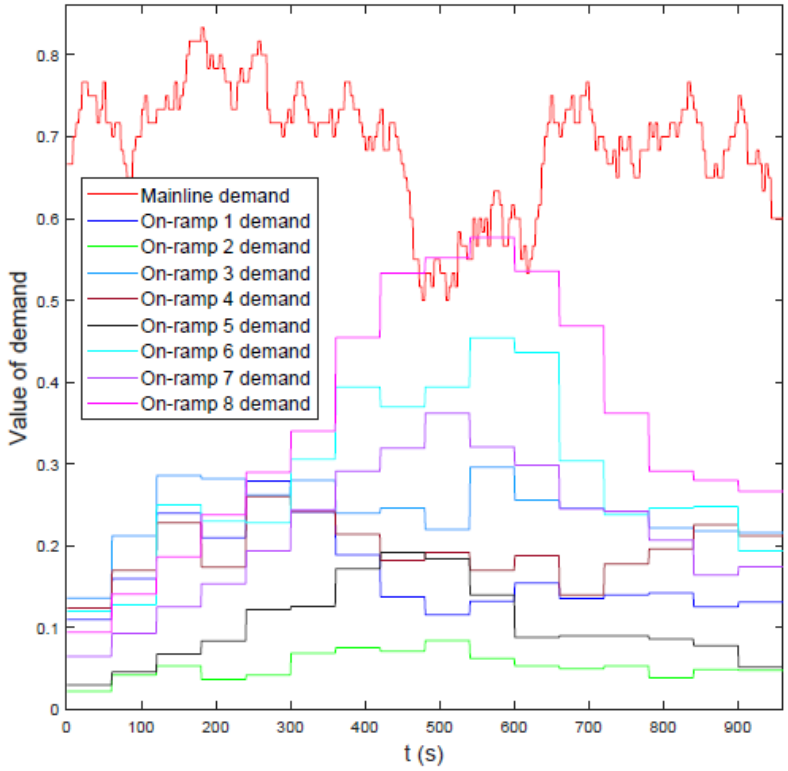
$$0 \le q_{j,t} \le q_{max}, \forall j, t.$$

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

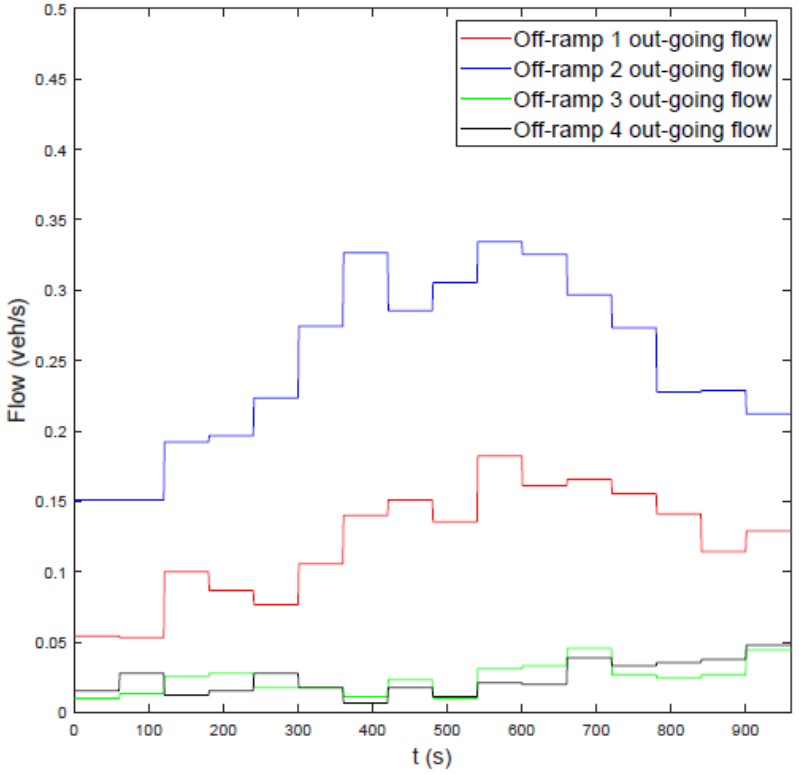
Model Predictive Control (MPC)



Demand flows and out-going flows



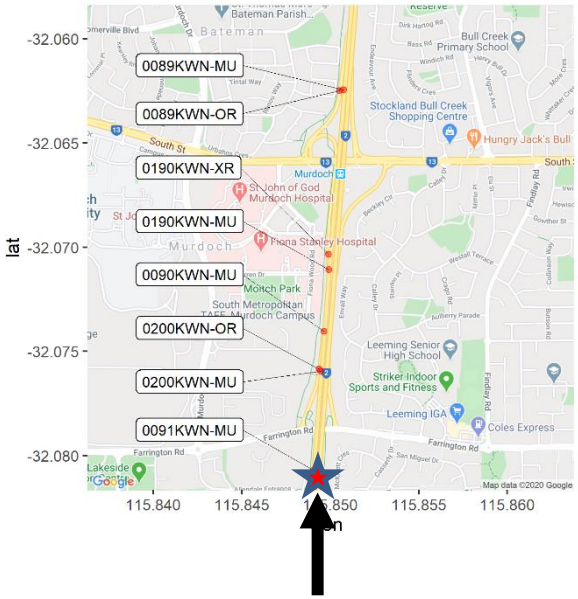
(a) Mainline demand and on-ramp demands

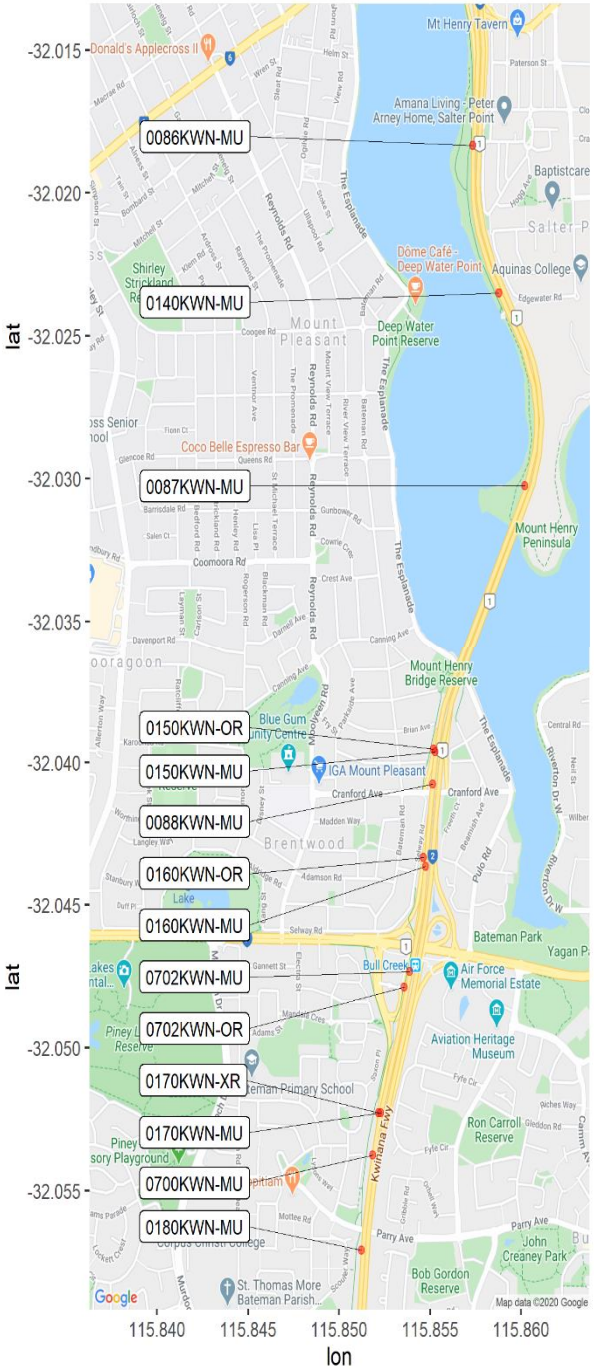


(b) Out-going flow

Microsimulation

Kwinana Network Model with 156 Detectors & 14 NPI links





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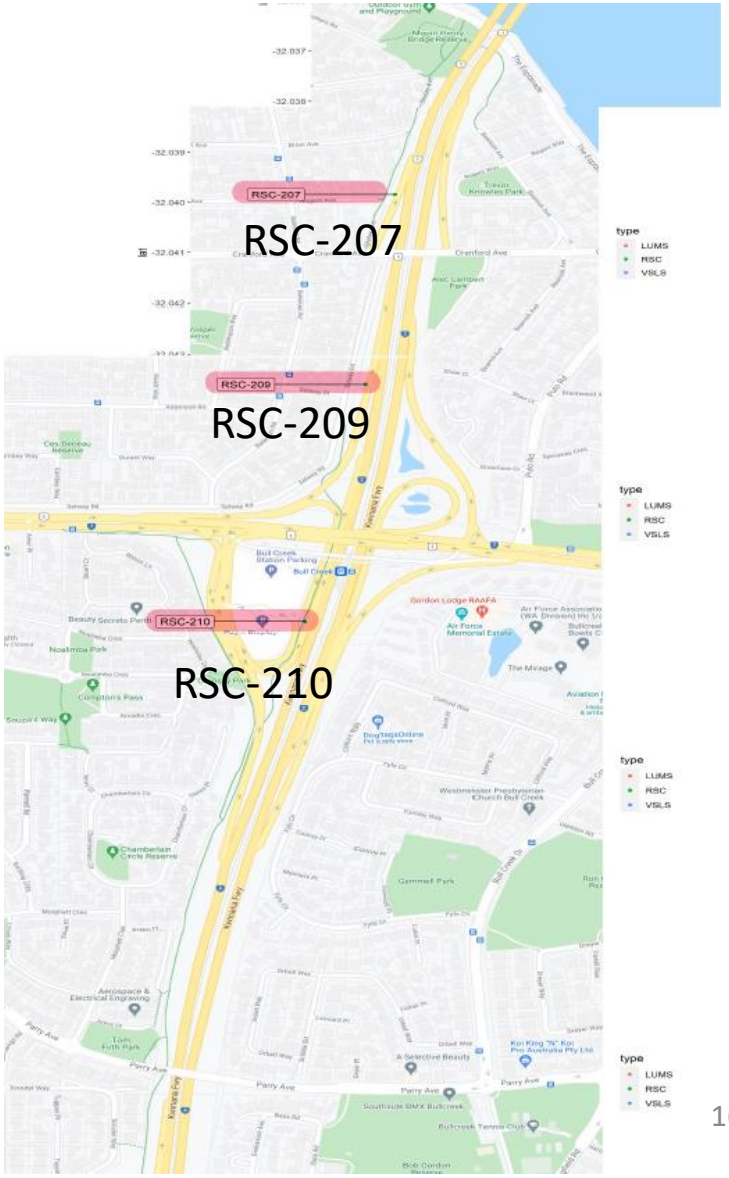
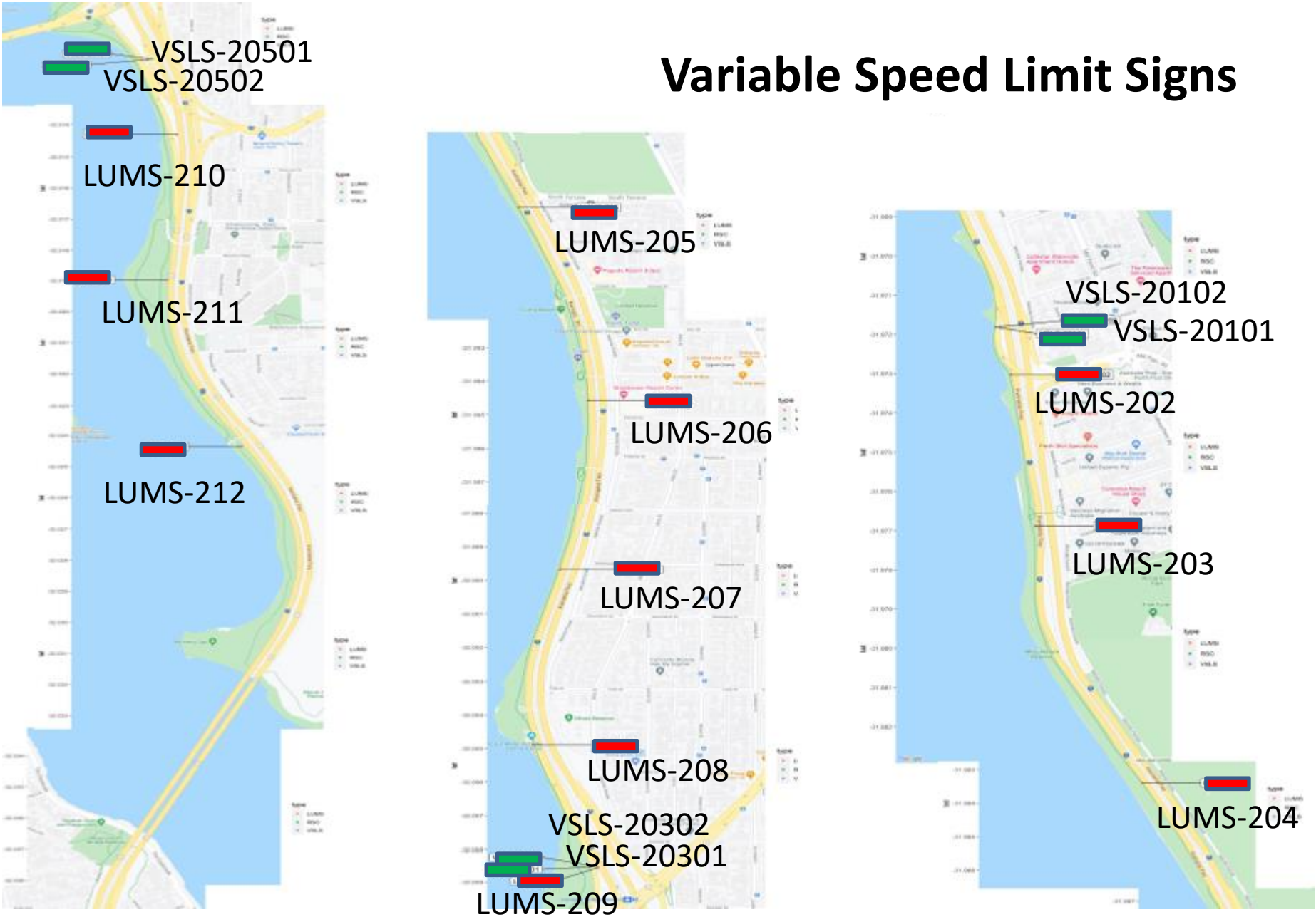
Ramp Metering Series



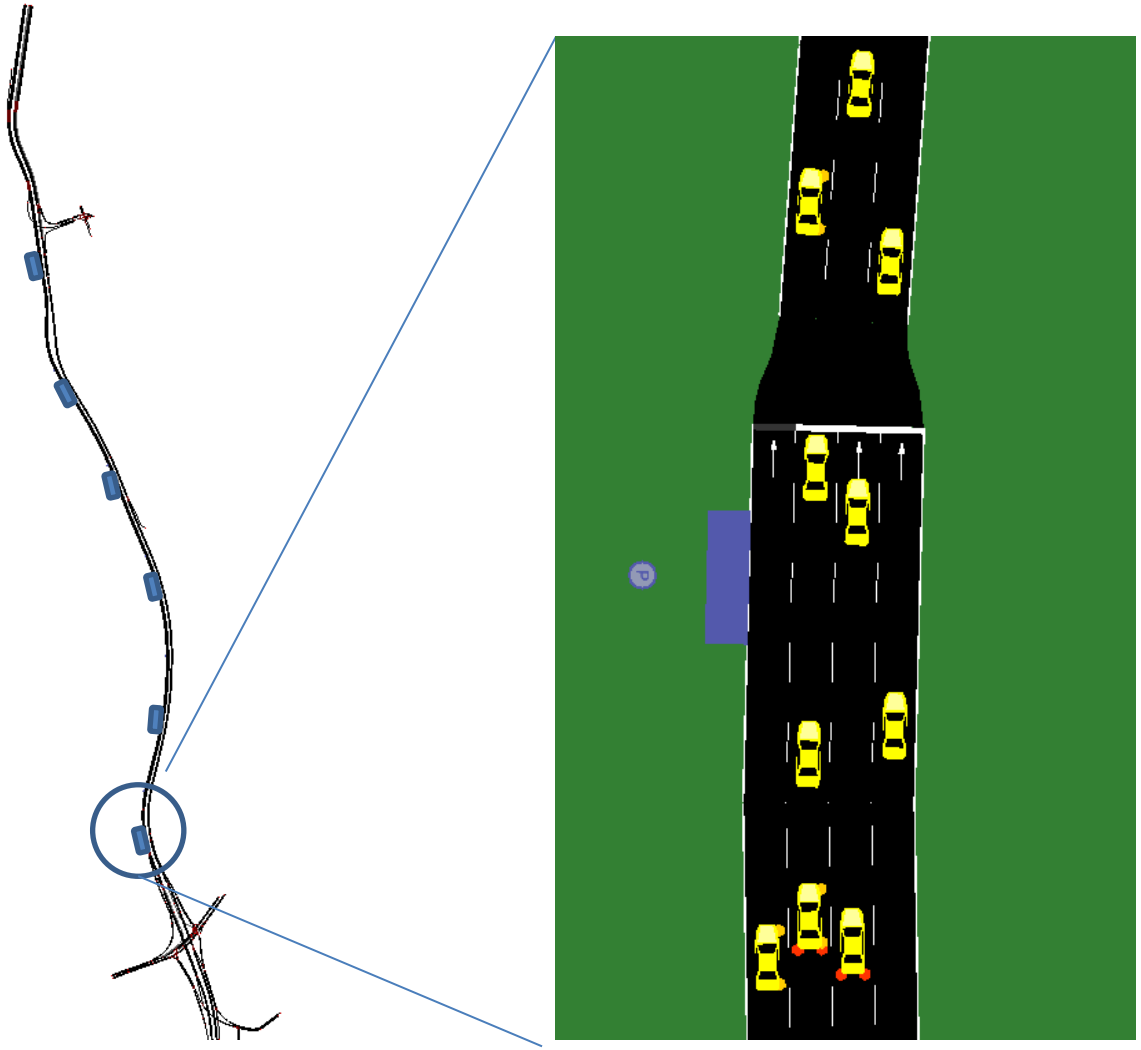
Variable Speed Limit Signs



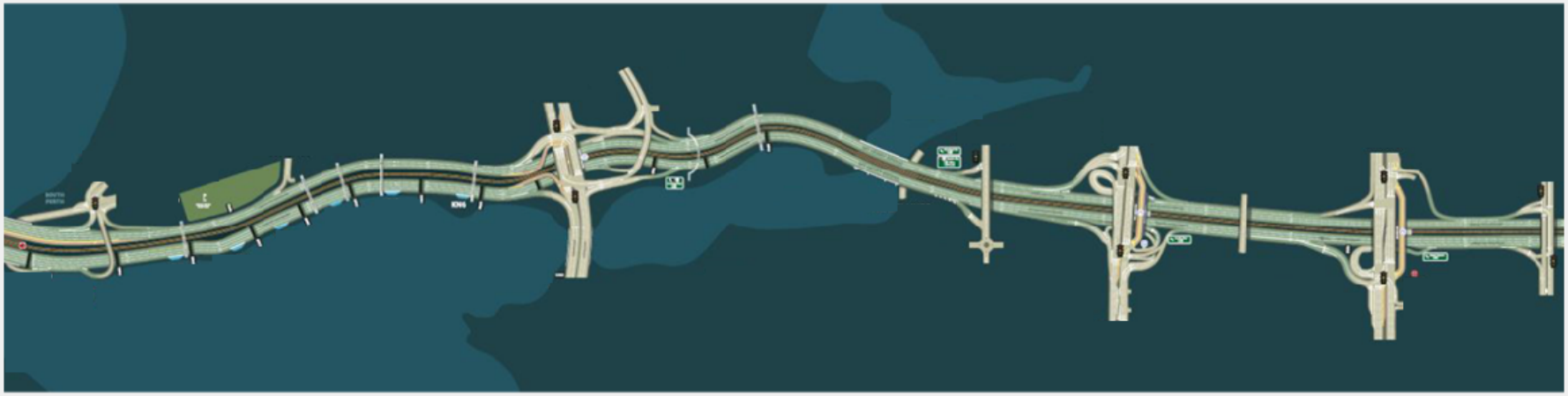
VSLS

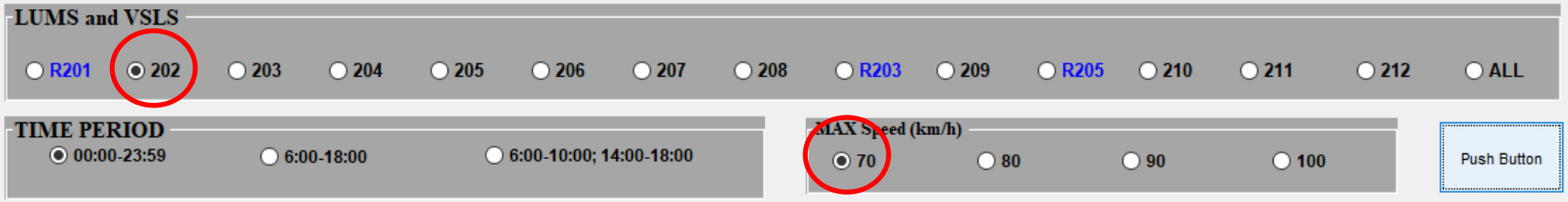
LUMS

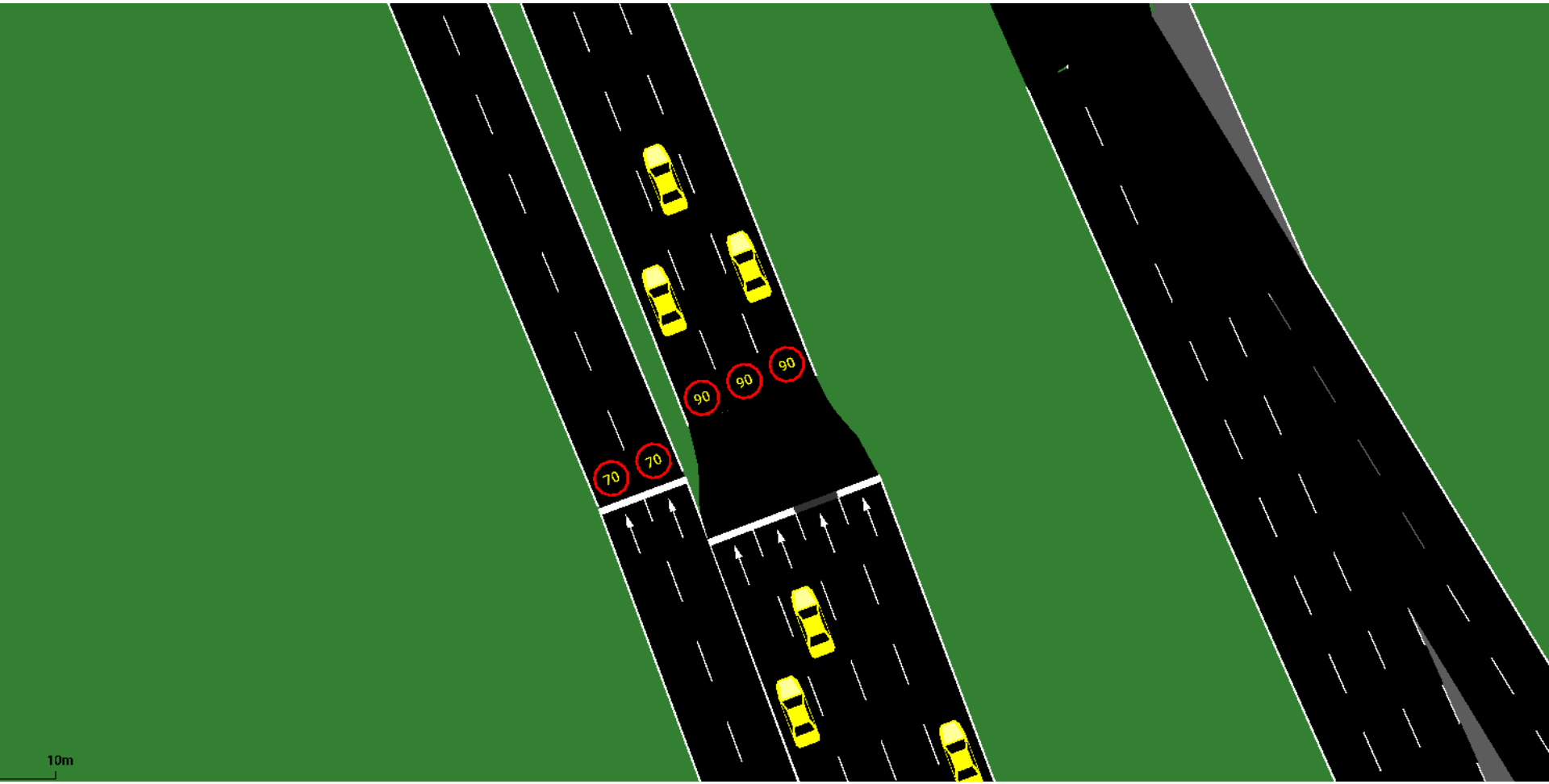
6 Parking areas



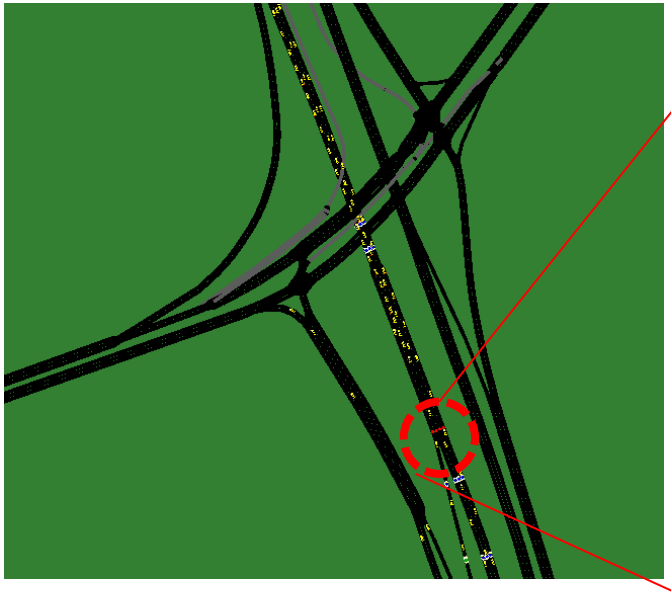
VSL Application Design

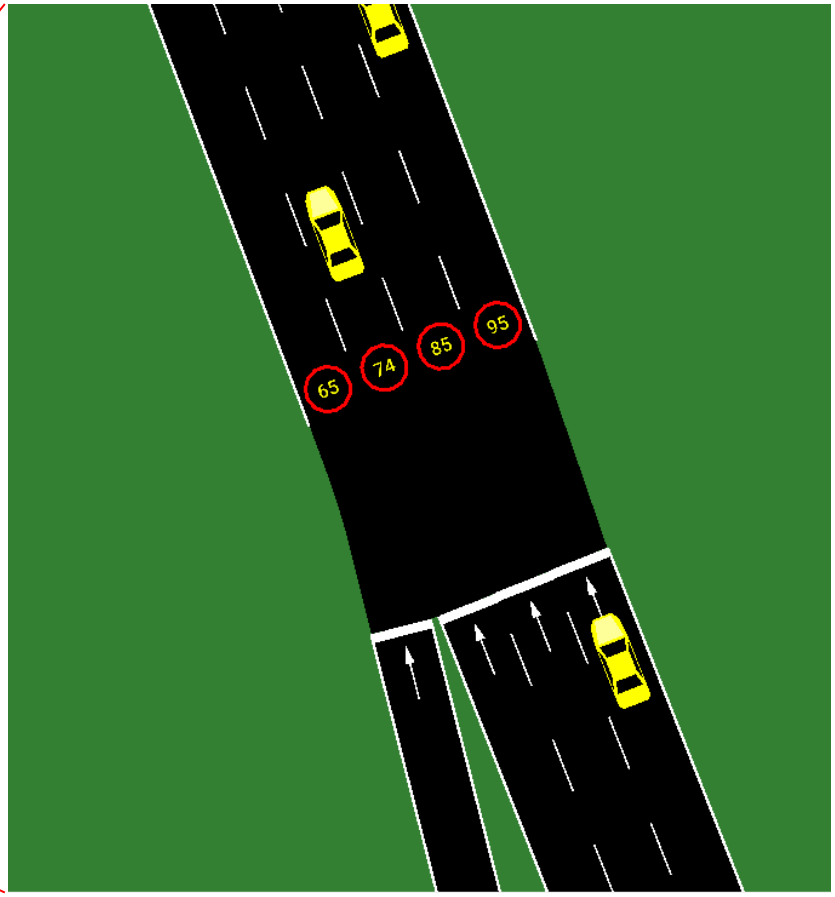


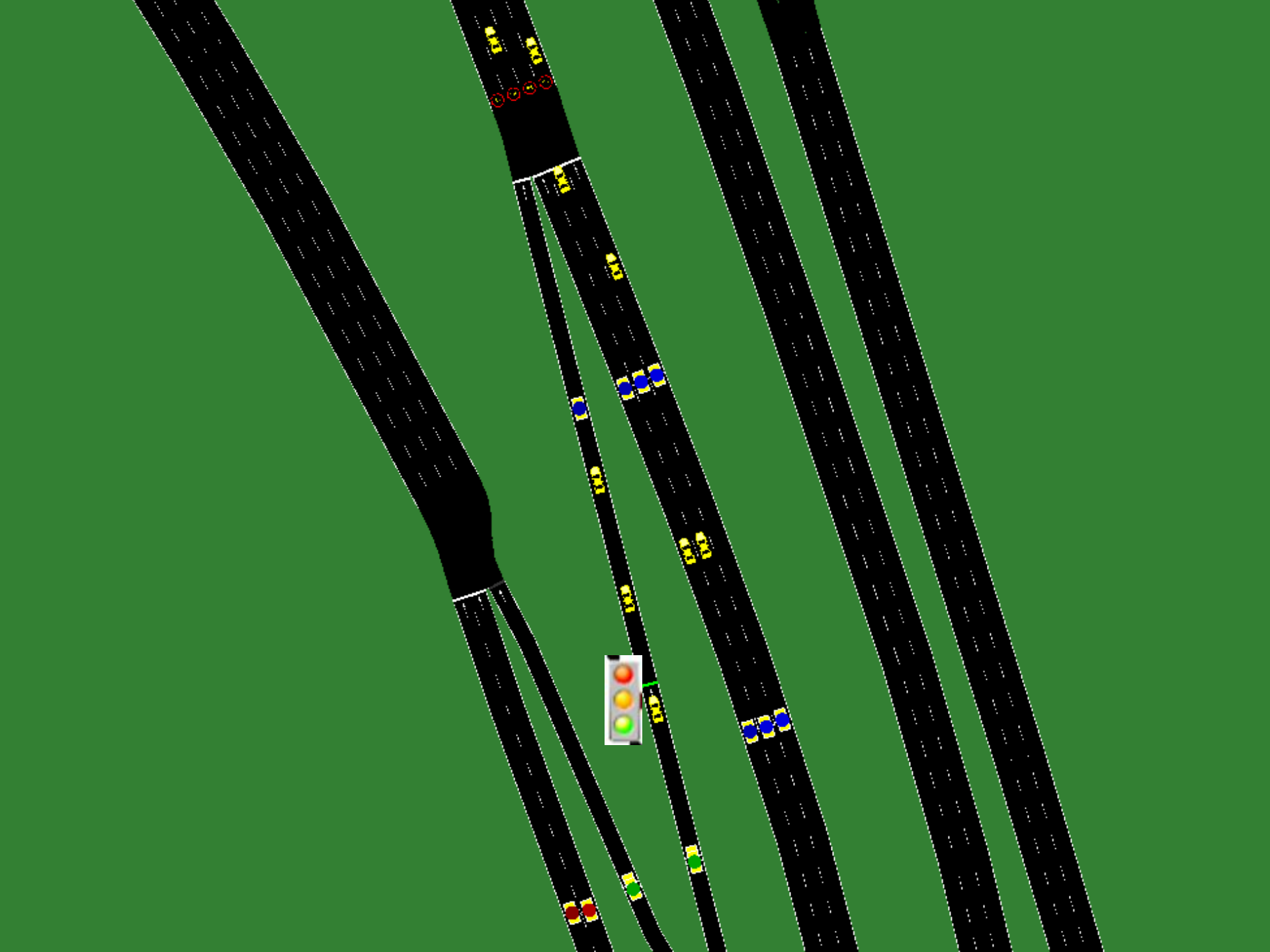




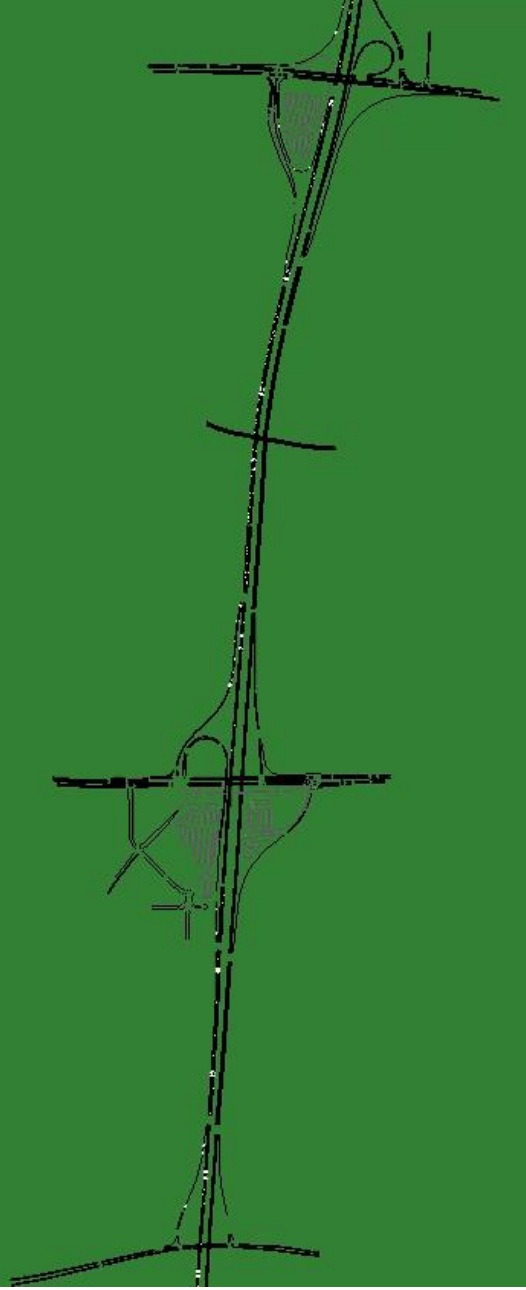
VSLS (70 km/h) and LUMS (90 km/h)

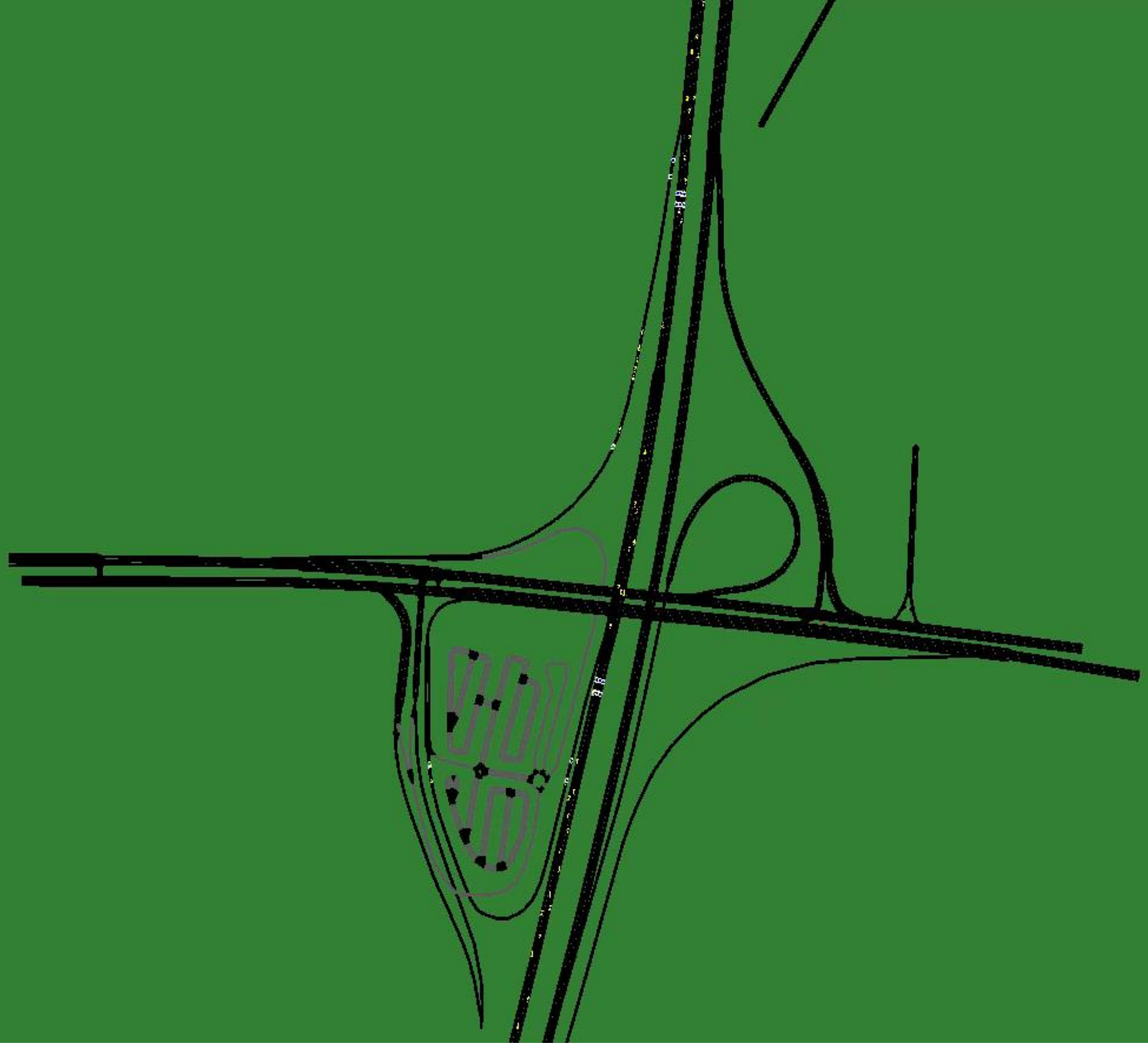


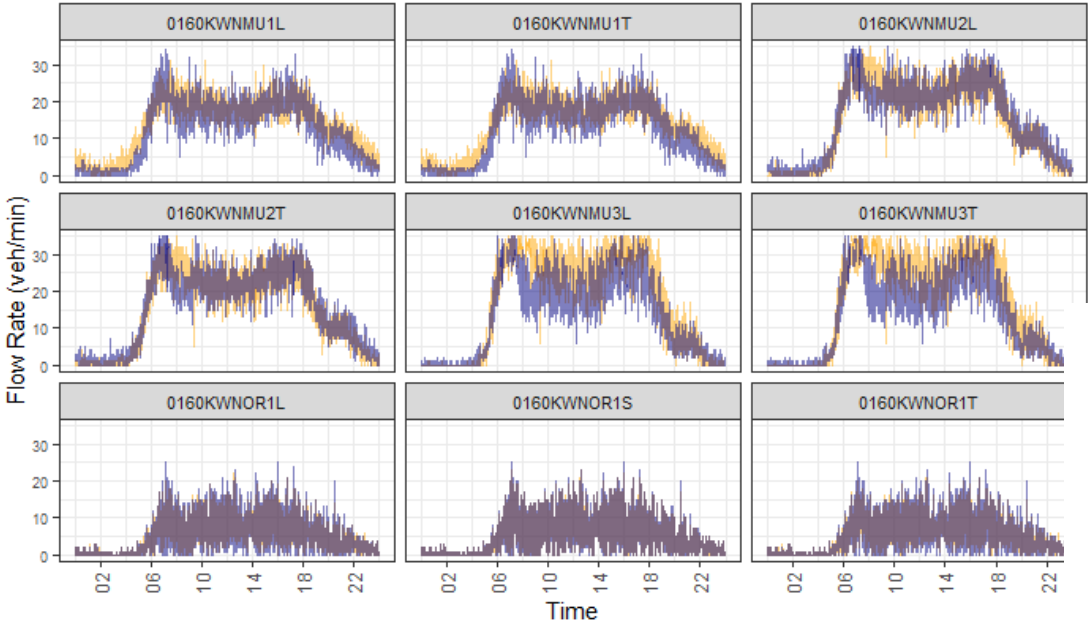

65
74
85
95

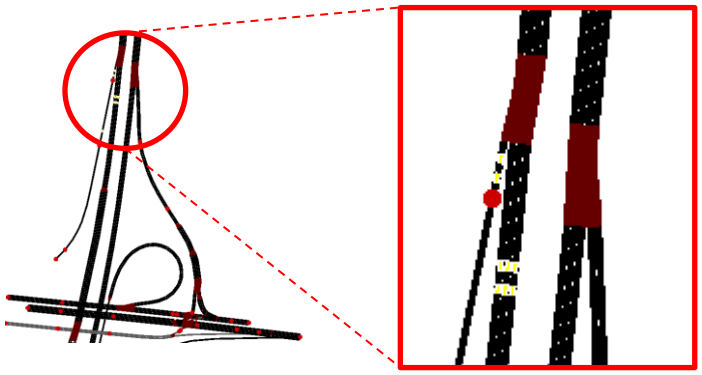


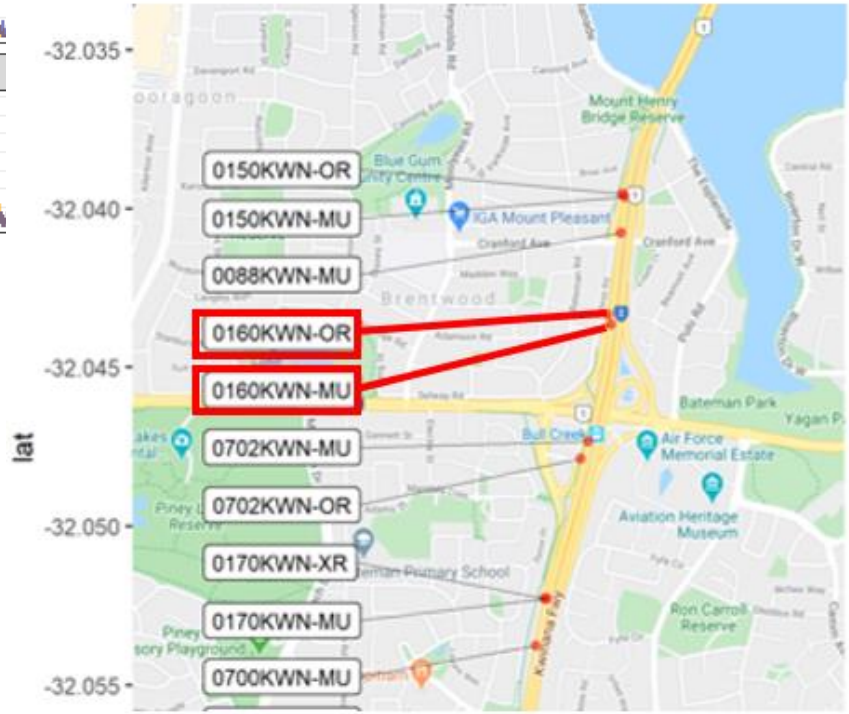

Cassey St
McDougall St
Bus Ln
1
2
6
Canning Hwy
Edgecumbe St
Tulip Ln
Manning Rd
Microsimulation





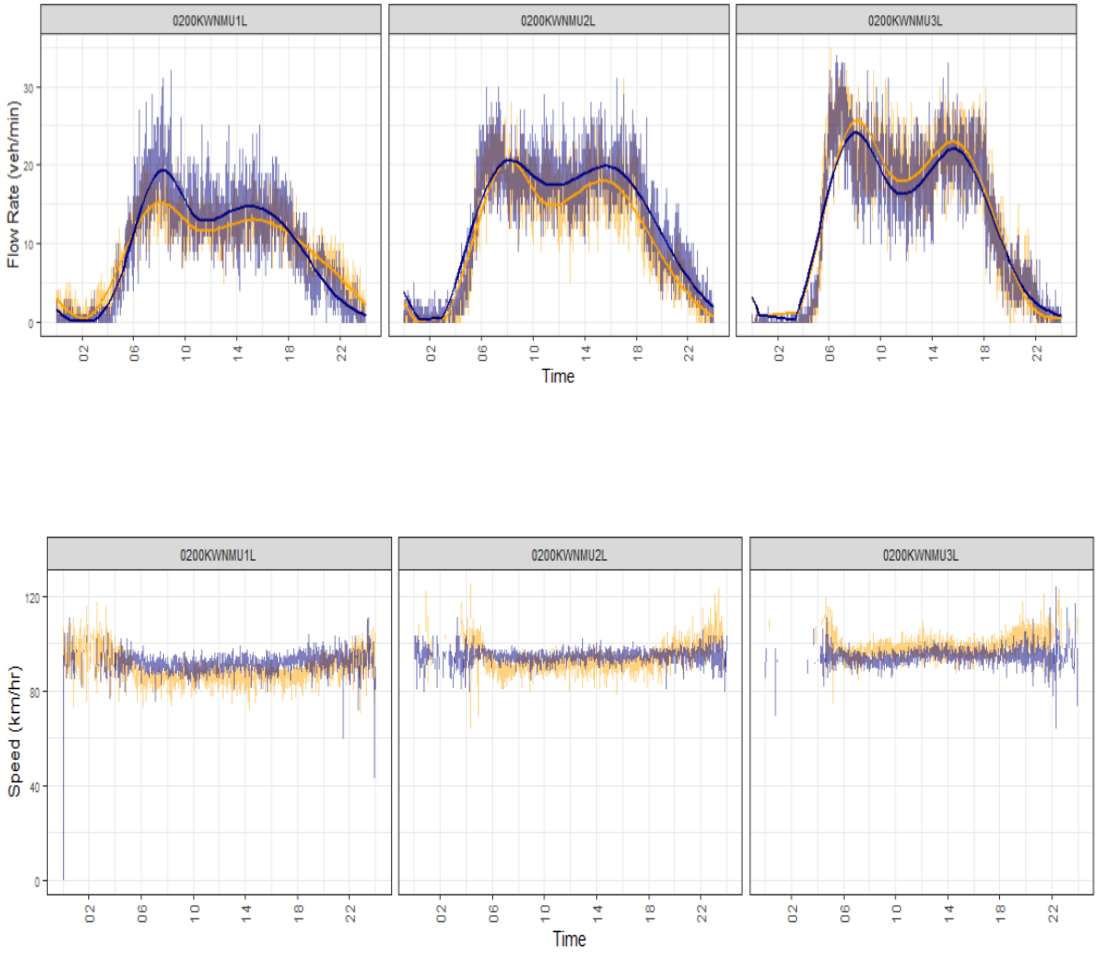

0160KWNMU1L
0160KWNMU1T
0160KWNMU2L
0160KWNMU2T
0160KWNMU3L
0160KWNMU3T
0160KWNOR1L
0160KWNOR1S
0160KWNOR1T
Flow Rate (veh/min)
Time

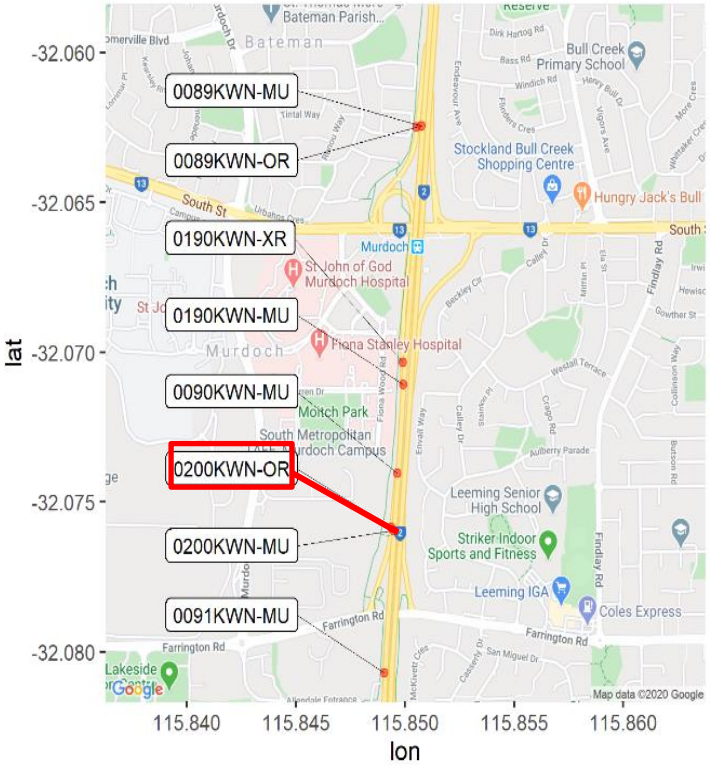



0150KWN-OR
0150KWN-MU
0088KWN-MU
0160KWN-OR
0160KWN-MU
0702KWN-MU
0702KWN-OR
0170KWN-XR
0170KWN-MU
0700KWN-MU
lat

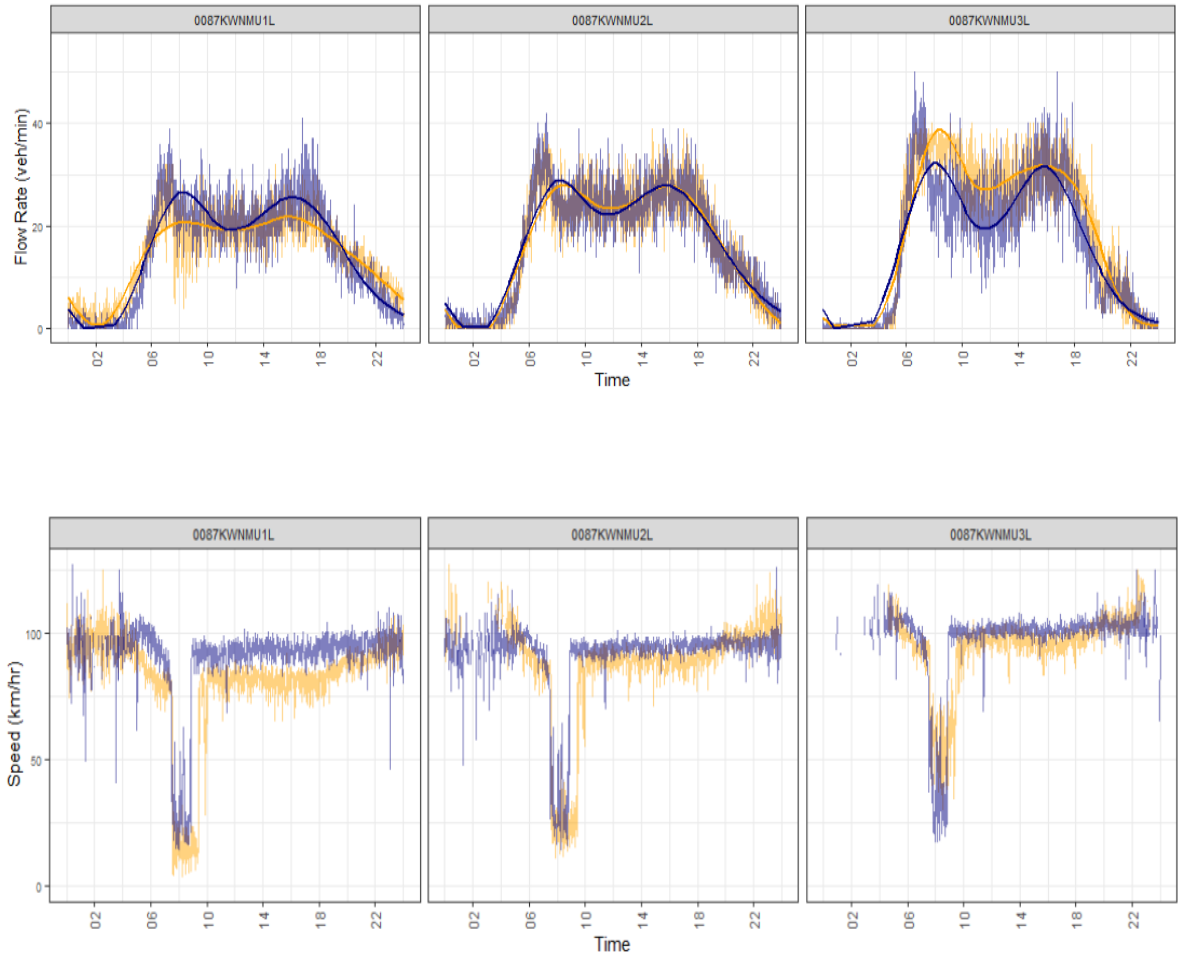
Leach Hwy

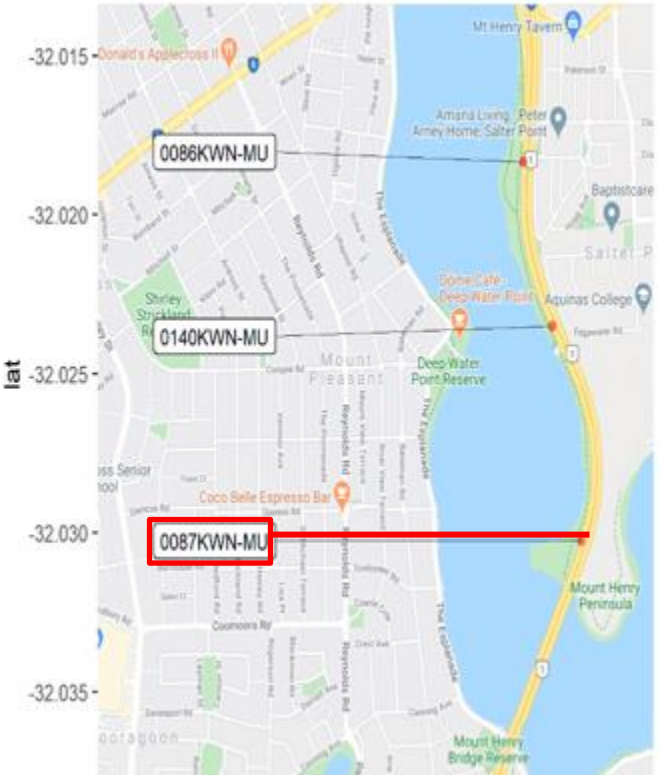
0200KWN: Lanes 1, 2 and 3



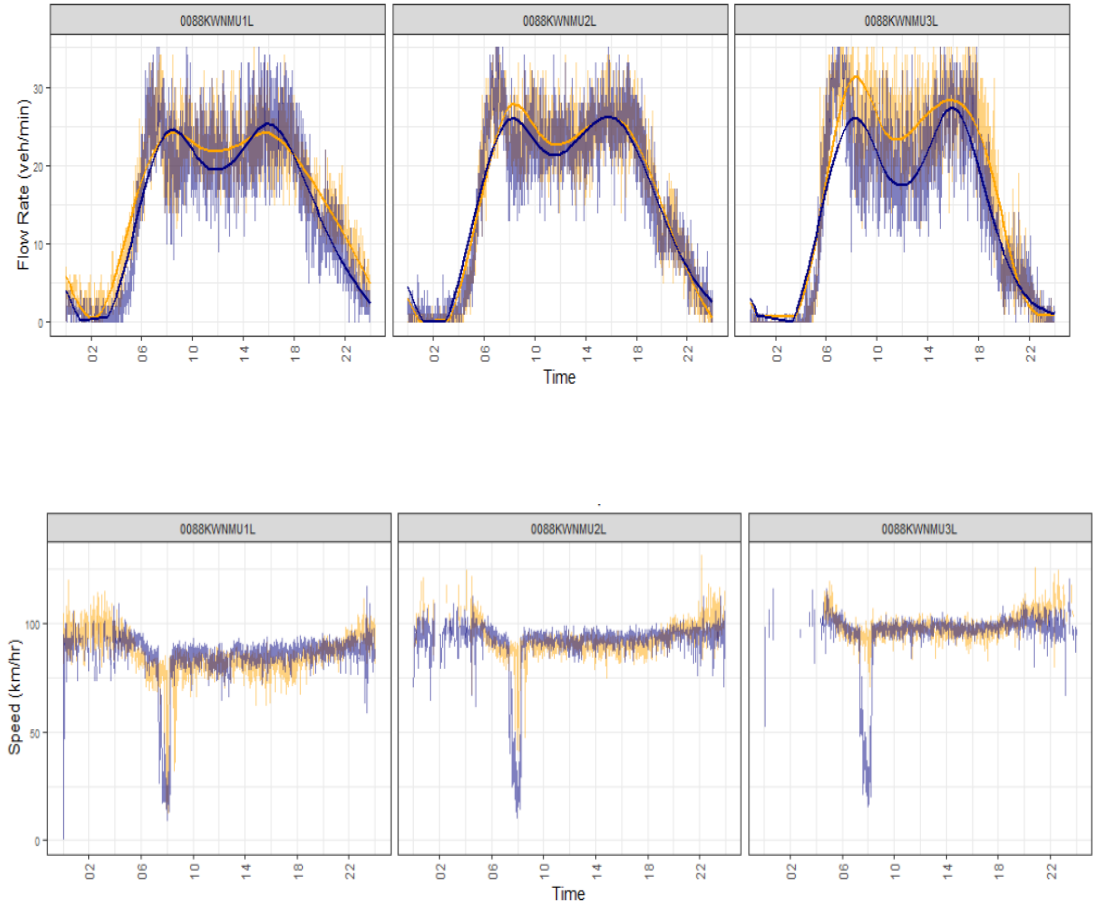


0087KWN: Lanes 1, 2 and 3



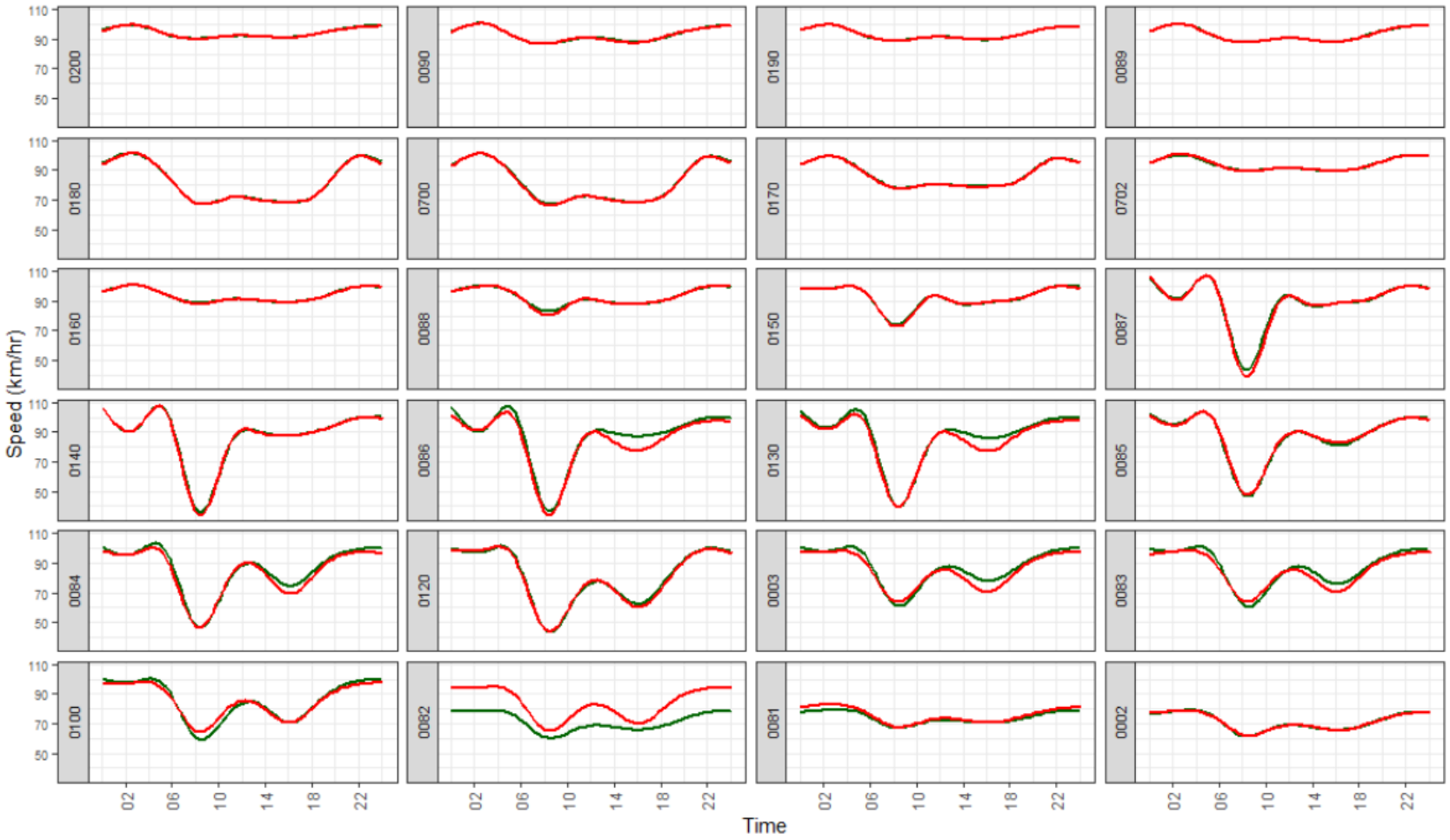


0088KWN: Lanes 1, 2 and 3

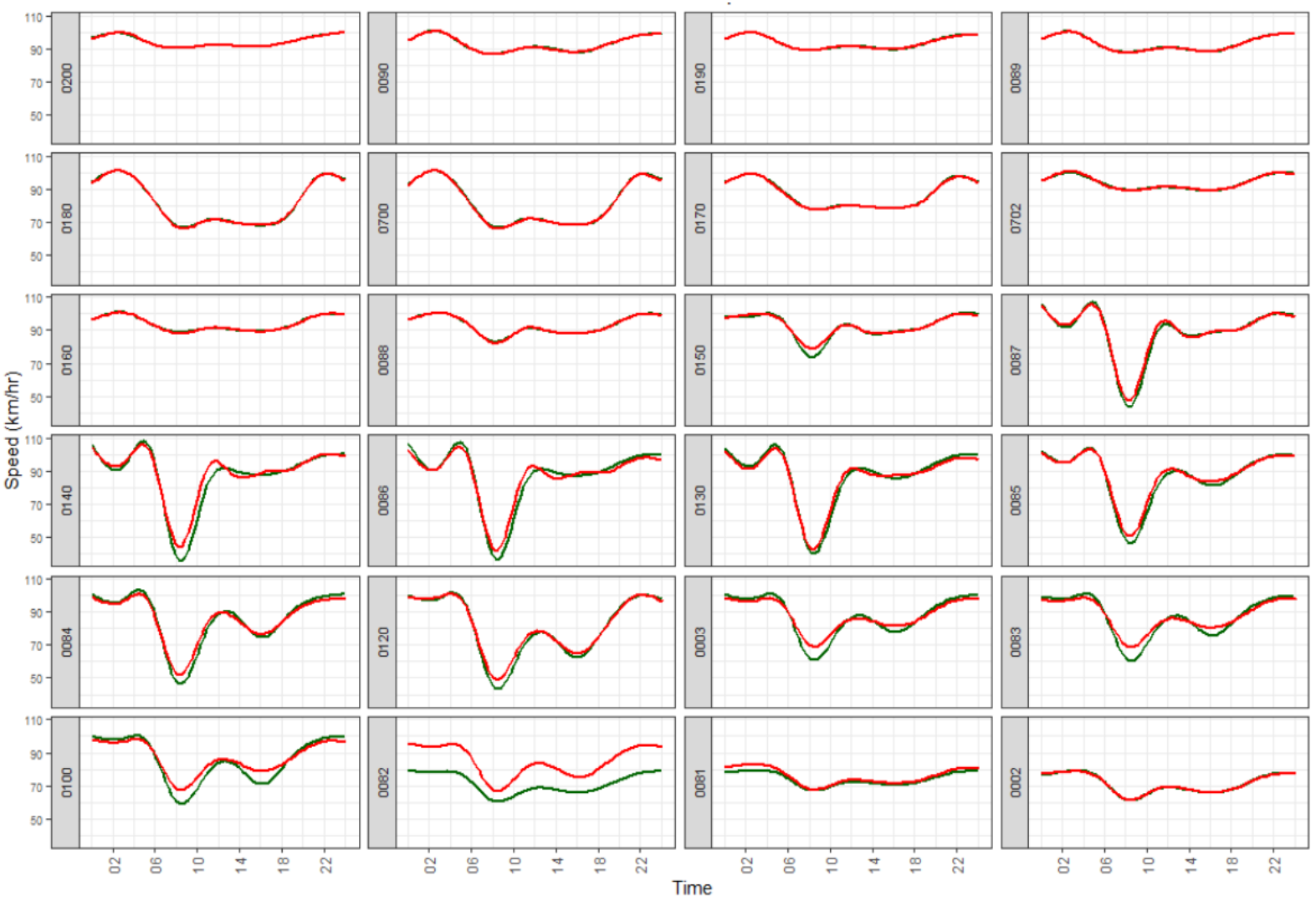


VSL Scheme	Ramp Metering (90 sec per cycle)	LUMS Speed	VSLS Speed
1	80 G| 5 Y| 5 R	90	70
2	80 G| 5 Y| 5 R	100	70
3	RSC - I	90	70
4	RSC - I	100	70

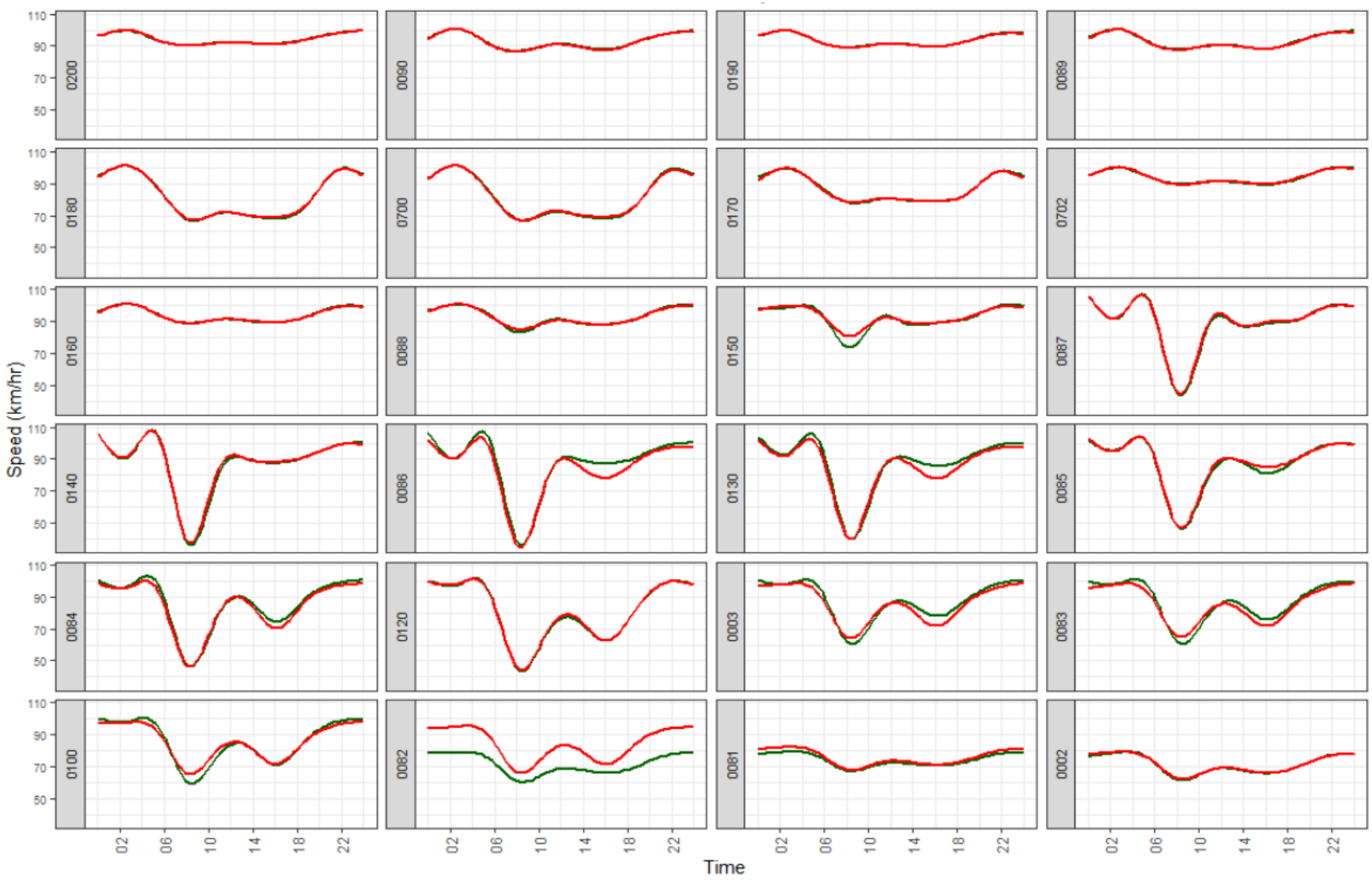
LUMS 90 & VSLS 70



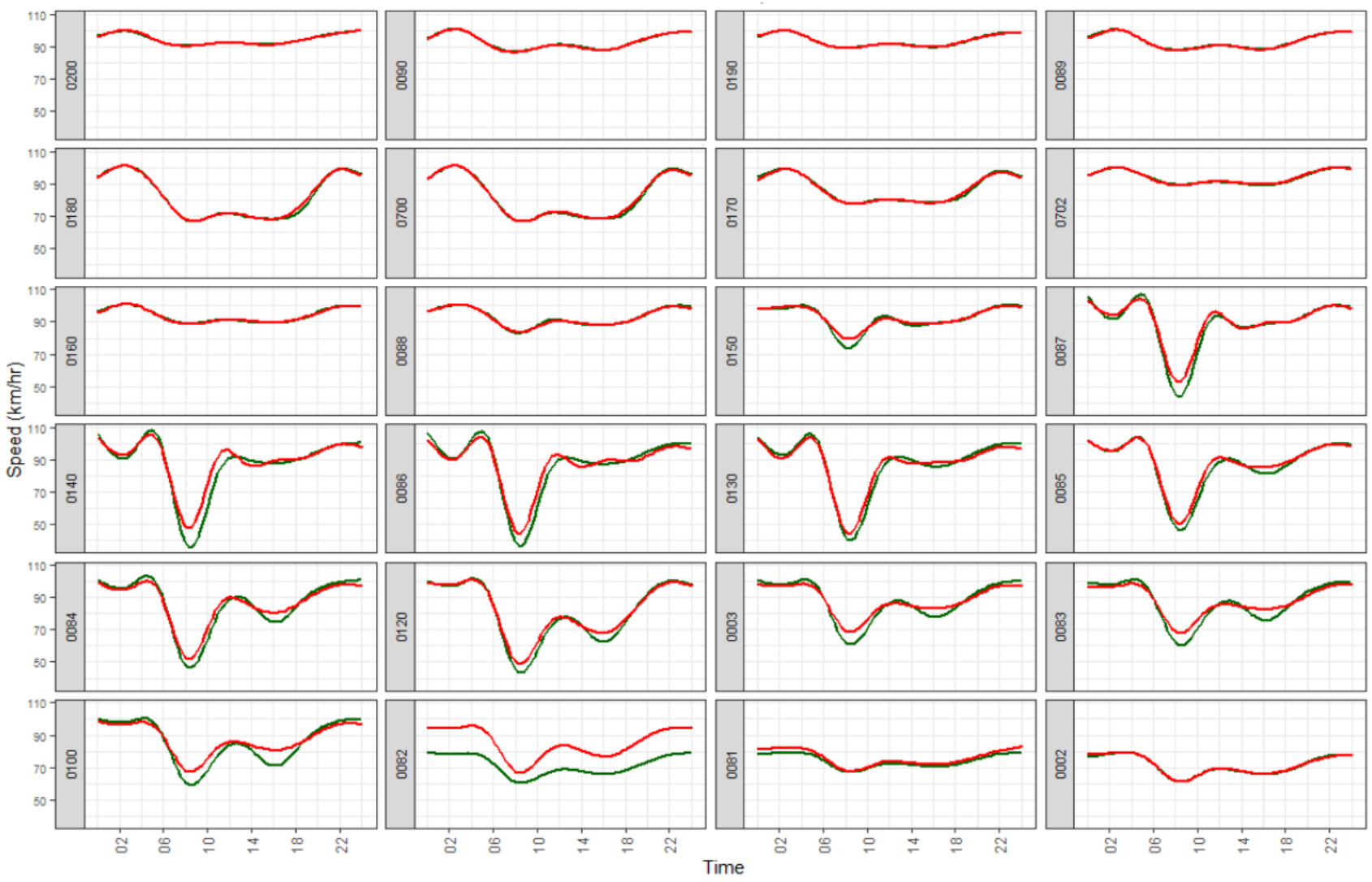
LUMS 100 & VSLS 70

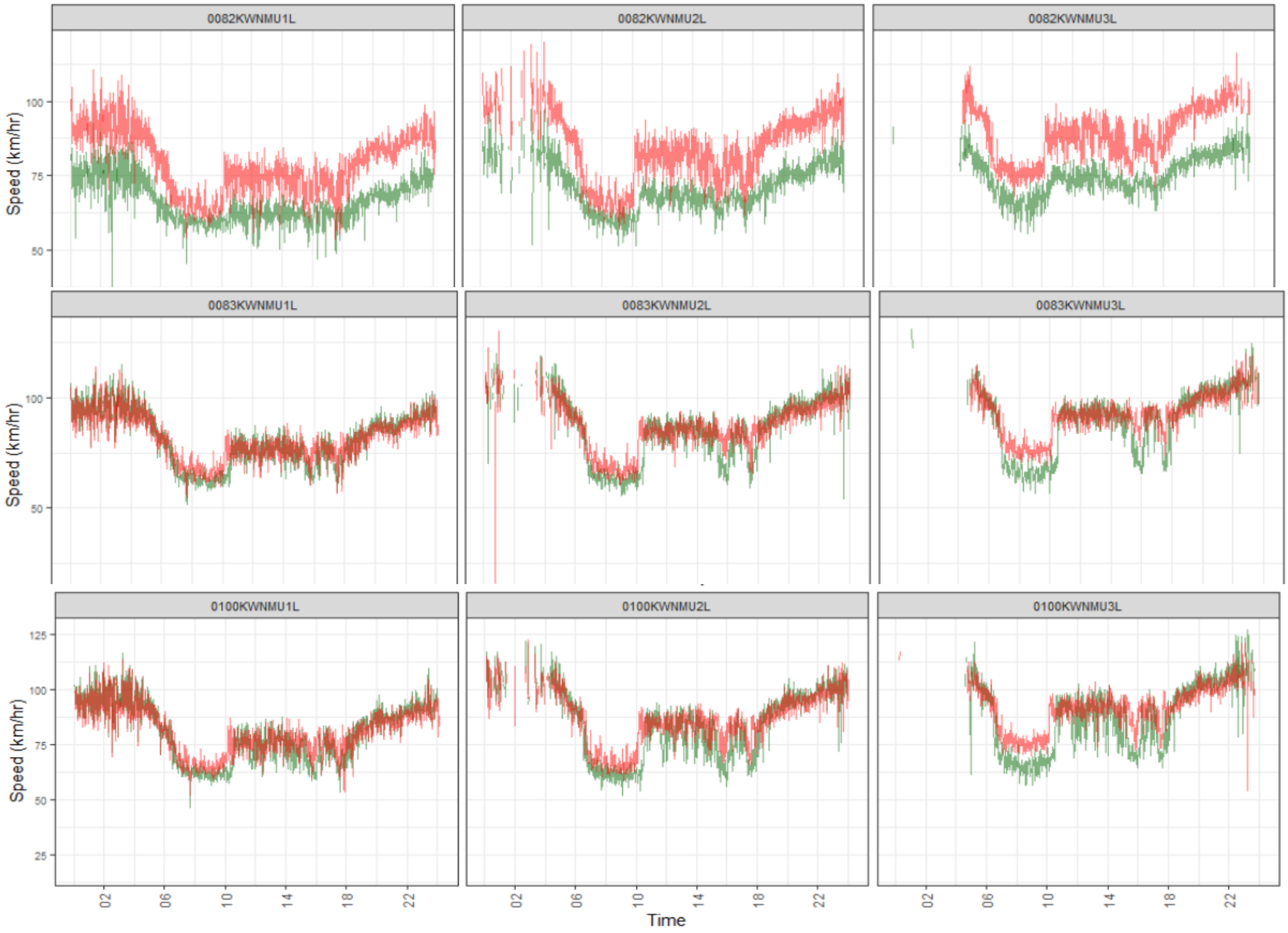


LUMS 90 & VSLS 70 & RSC1 (from 6 AM)



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




0082KWNMU1L
0082KWNMU2L
0082KWNMU3L
0083KWNMU1L
0083KWNMU2L
0083KWNMU3L
0100KWNMU1L
0100KWNMU2L
0100KWNMU3L
Speed (km/hr)
Time
02
06
10
14
18
22

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

THANK YOU

For Your Attention