Attachment E A, C, D

On Simulation and Optimization of Freeway Network Operations

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Progress from last PSG meeting

- Optimization of freeway traffic flow via ramp metering
- Microscopic simulation with VSL and RM based on traffic date & ALINEA – HERO algorithms
- Further data analysis: traffic prediction by CNN-LSTM

1. Optimization of freeway traffic flow via ramp metering

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

Road map:

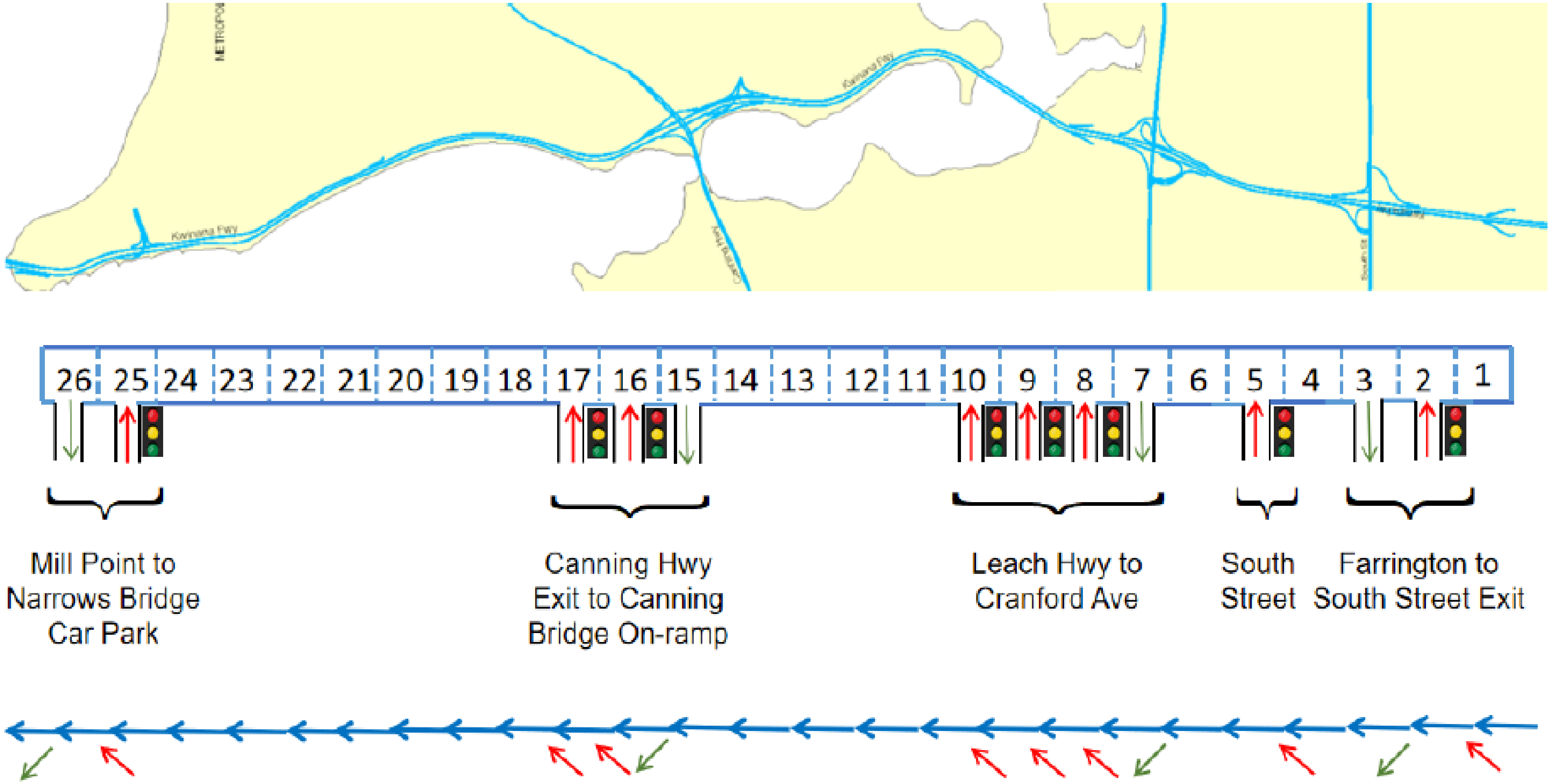


Figure 1

Model Predictive Control (MPC)

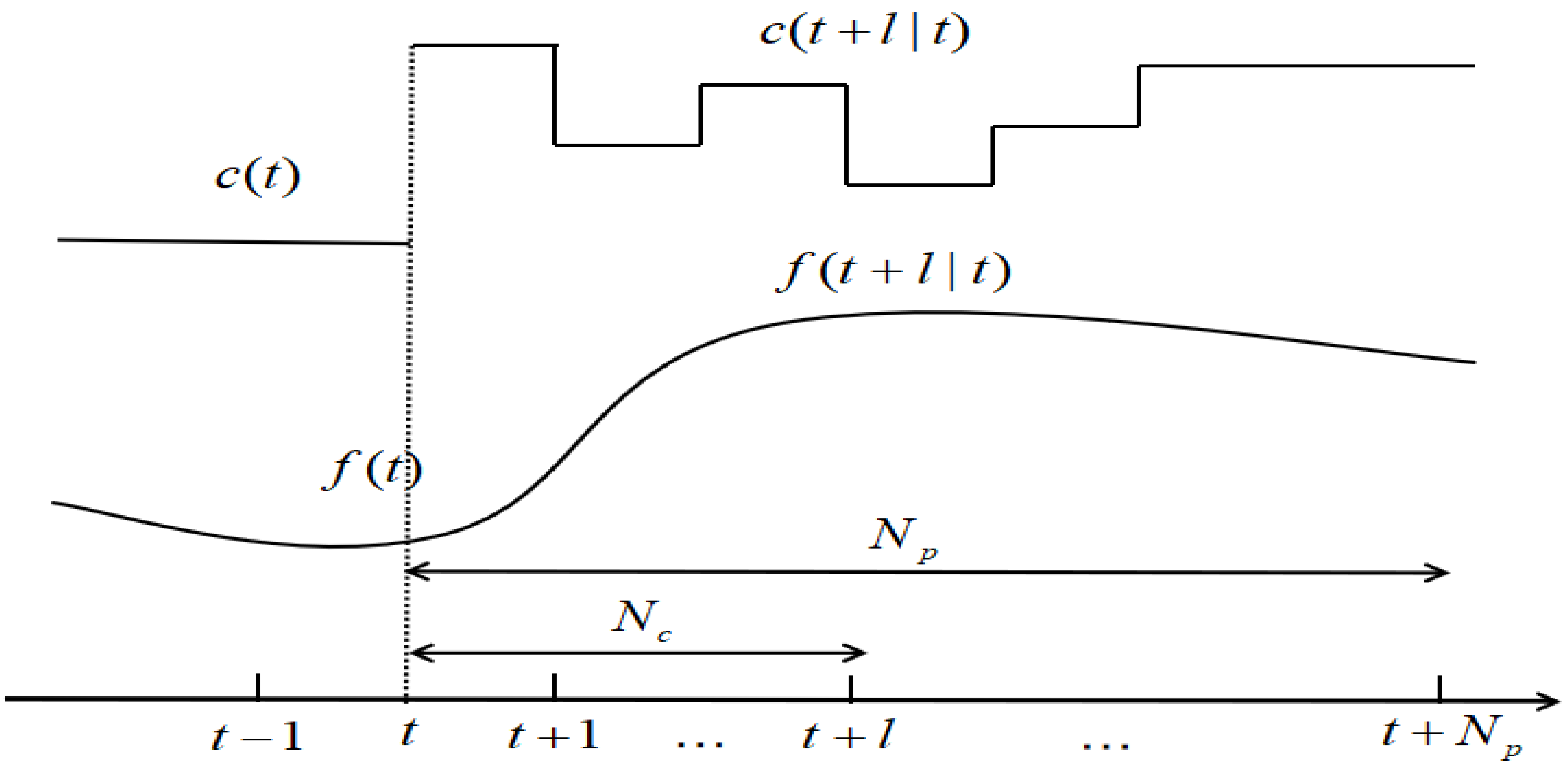


Figure 2

Model with capacity drop for ramp metering:

$$(\mathrm{DP}) \min_{\mathbf{r}} Z = \sum_{t=1}^{N_p-1} \sum_{i=1}^{I} (\rho_{i,t} \Delta L_i \Delta T + q_{i,t} \Delta T) + \lambda_r \sum_{t=2}^{N_p-1} \sum_{i=1}^{I} (r_{i,t} - r_{i,t-1})^2$$

s.t

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

$$f_{i,t} = \min\{f_{i,t}^D, f_{i+1,t}^S - \theta r_{i+1,t}\}$$

$$f_{i,t}^D = \min\left\{ v_{f,i}\rho_{i,t}, \quad \left[Q_i + \alpha Q_i \left(\frac{\rho_{i,t} - \rho_{cr,i}}{\rho_{cr,i} - \rho_{max,i}} \right) \right] \right\}$$

$$f_{i+1,t}^S = \min\{Q_{i+1}, w_{i+1}(\rho_{max,i+1} - \rho_{i+1,t})\}$$

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

$$0 \leq q_{i,t} \leq q_{max,i}$$

$$0 \leq r_{i,t} \leq r_{max,i}$$

Total Time Spent (TTS)

the time-variations of the on-ramp flows

Figure 3

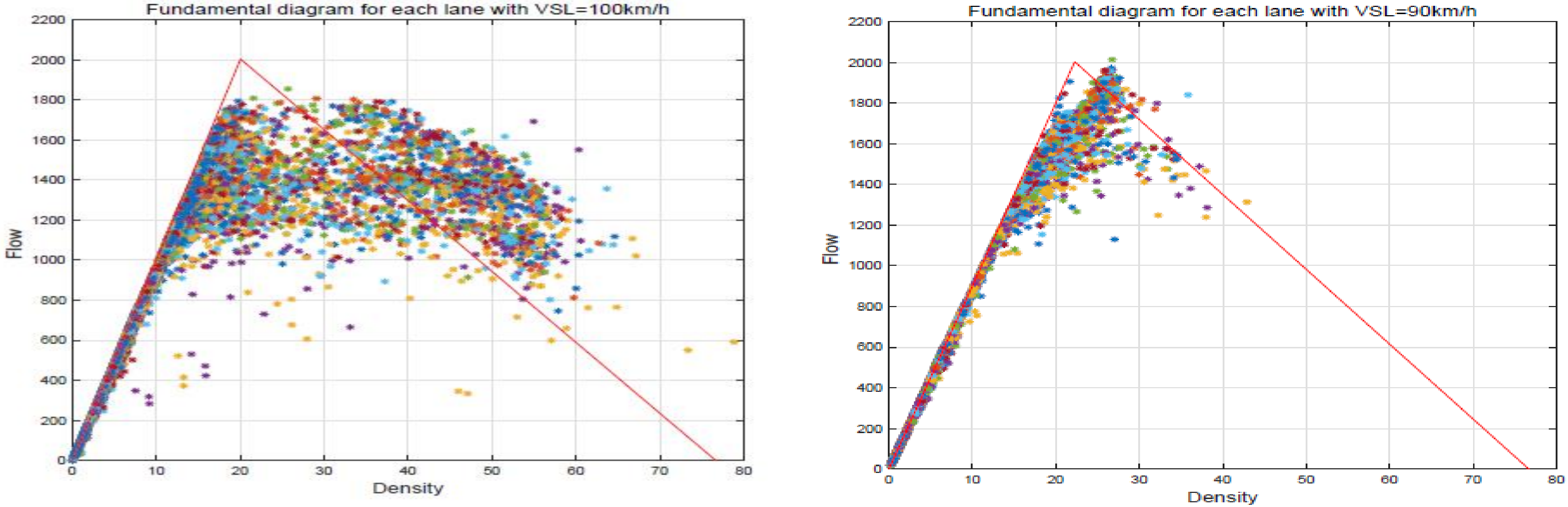
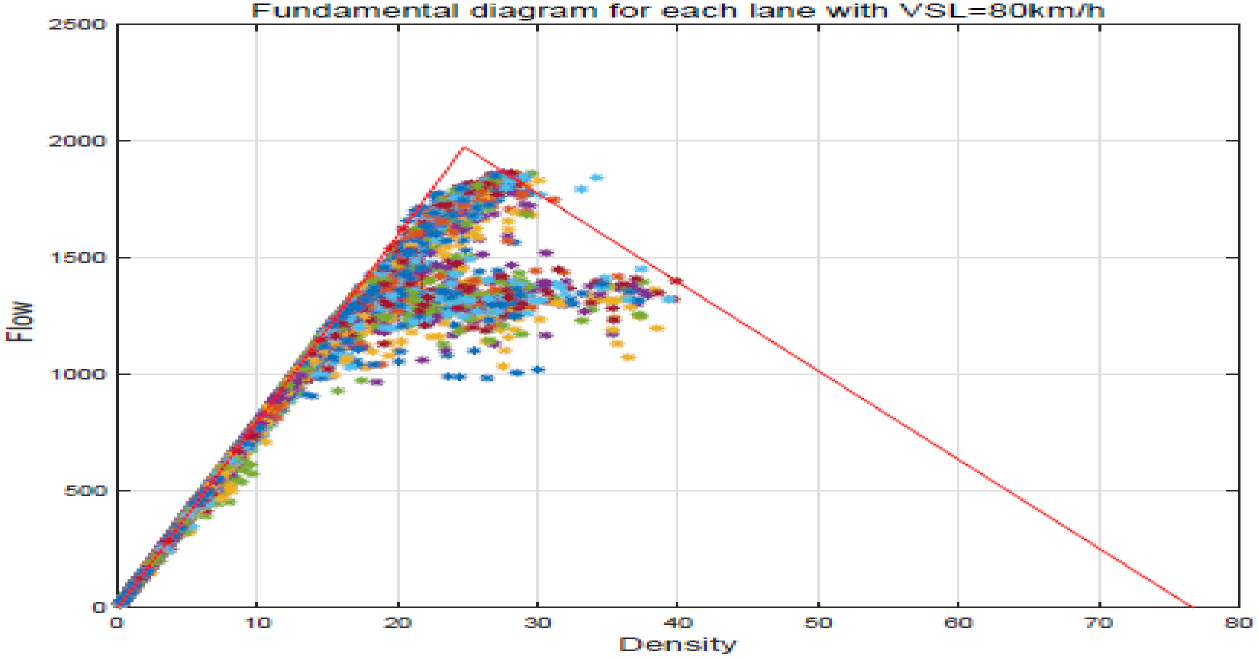

Fundamental diagram for each lane with VSL=100km/h
Flow
Density
Fundamental diagram for each lane with VSL=90km/h
Flow
Density

Fundamental diagram for each lane with VSL=80km/h
Flow
Density

Figure 4

Fundamental diagram with capacity drop

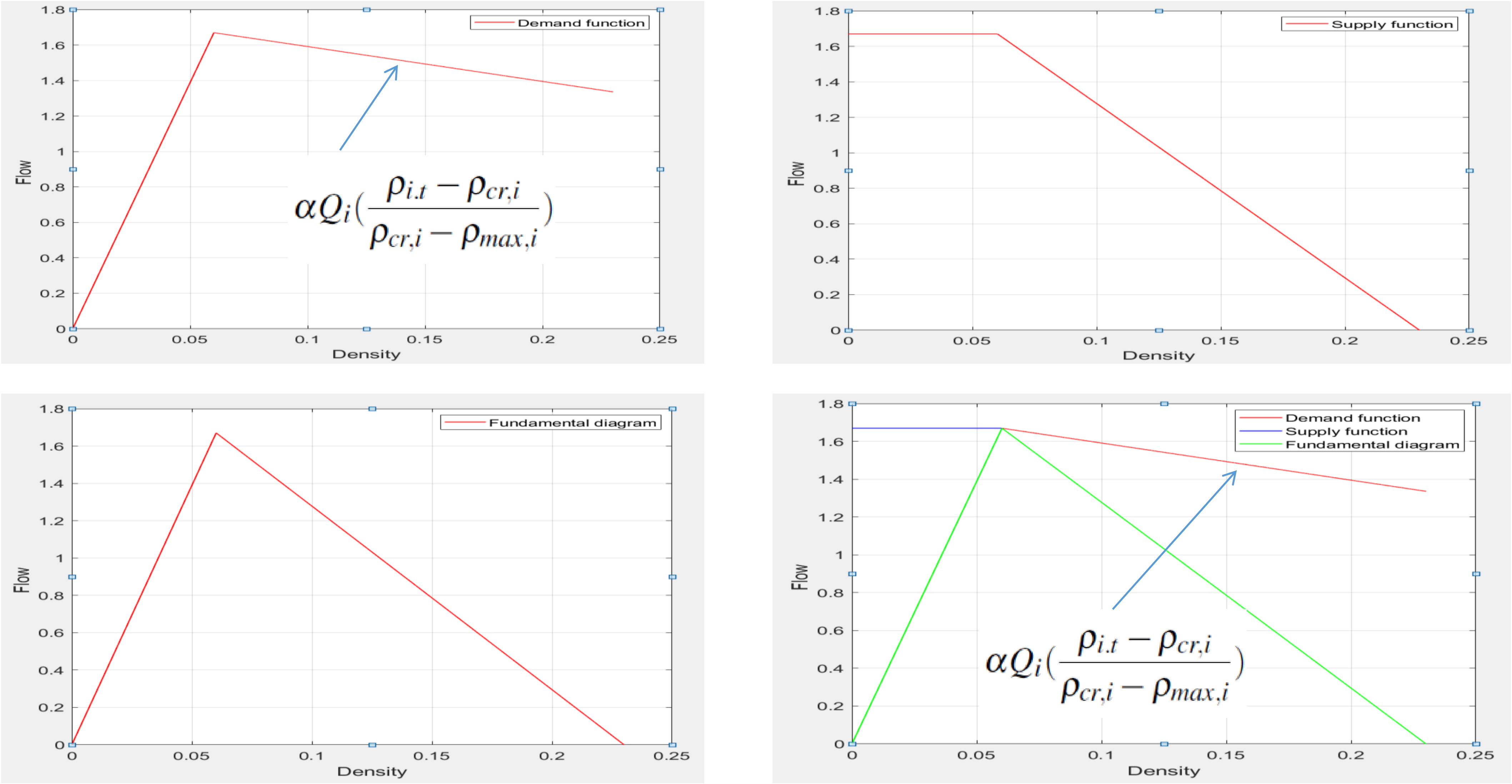


Figure 5

Comparison of measured data (with no RM) with computed results With RM:

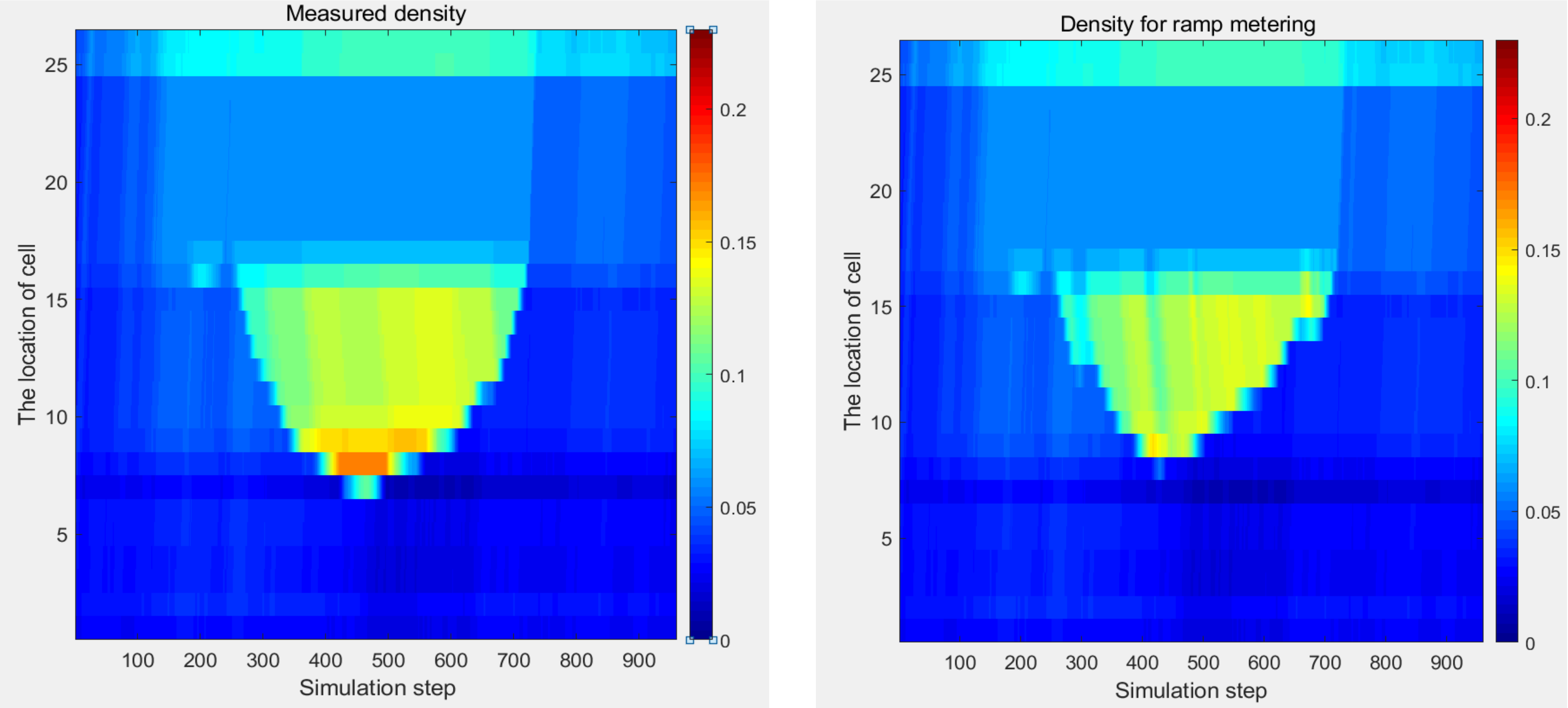
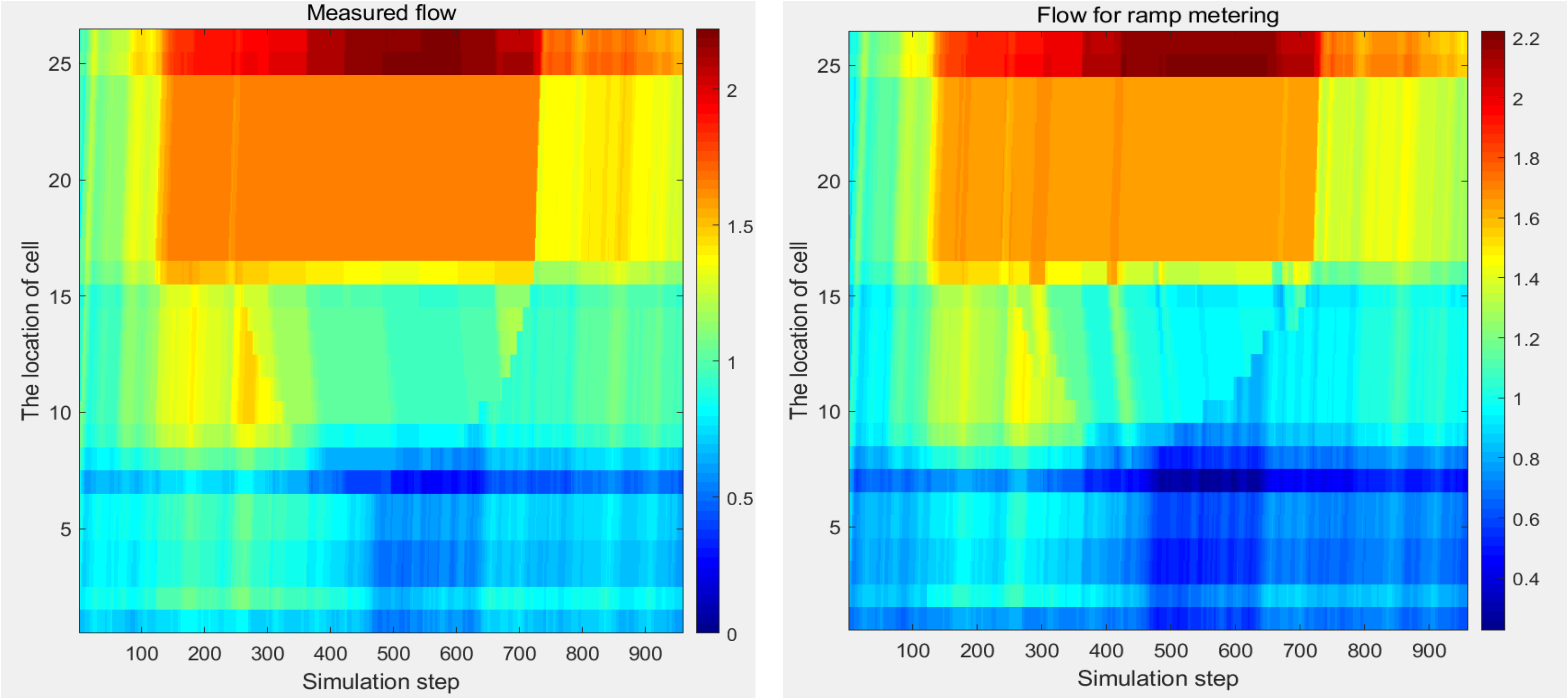


Figure 6



Measured flow
The location of cell
Simulation step
25
20
15
10
5
100
200
300
400
500
600
700
800
900
2
1.5
1
0.5
0
Flow for ramp metering
The location of cell
Simulation step
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4

Figure 7

Computed On-ramp Queue Lengths

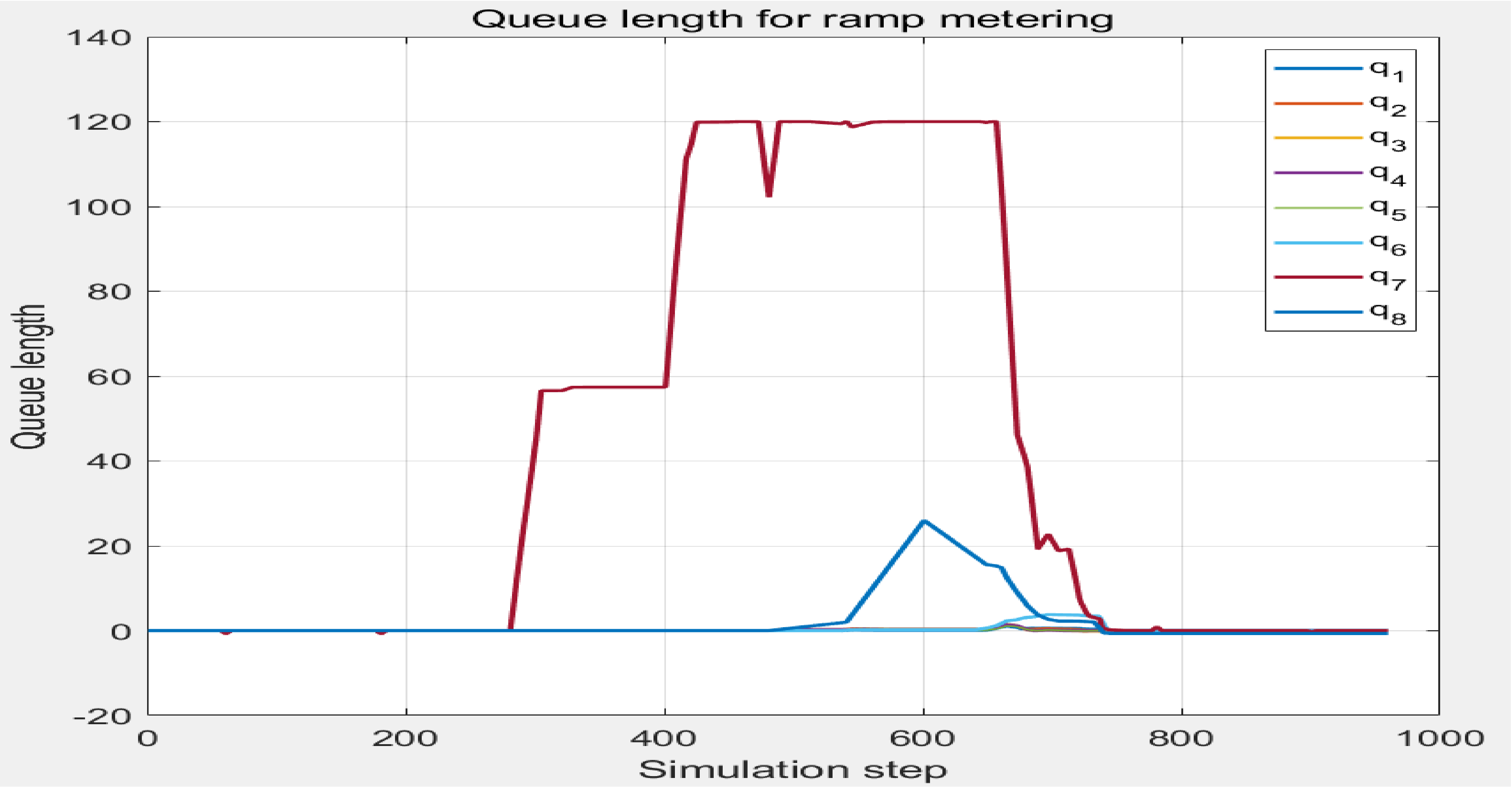


Figure 8

Comparison of demand and RM for each of the on-ramps

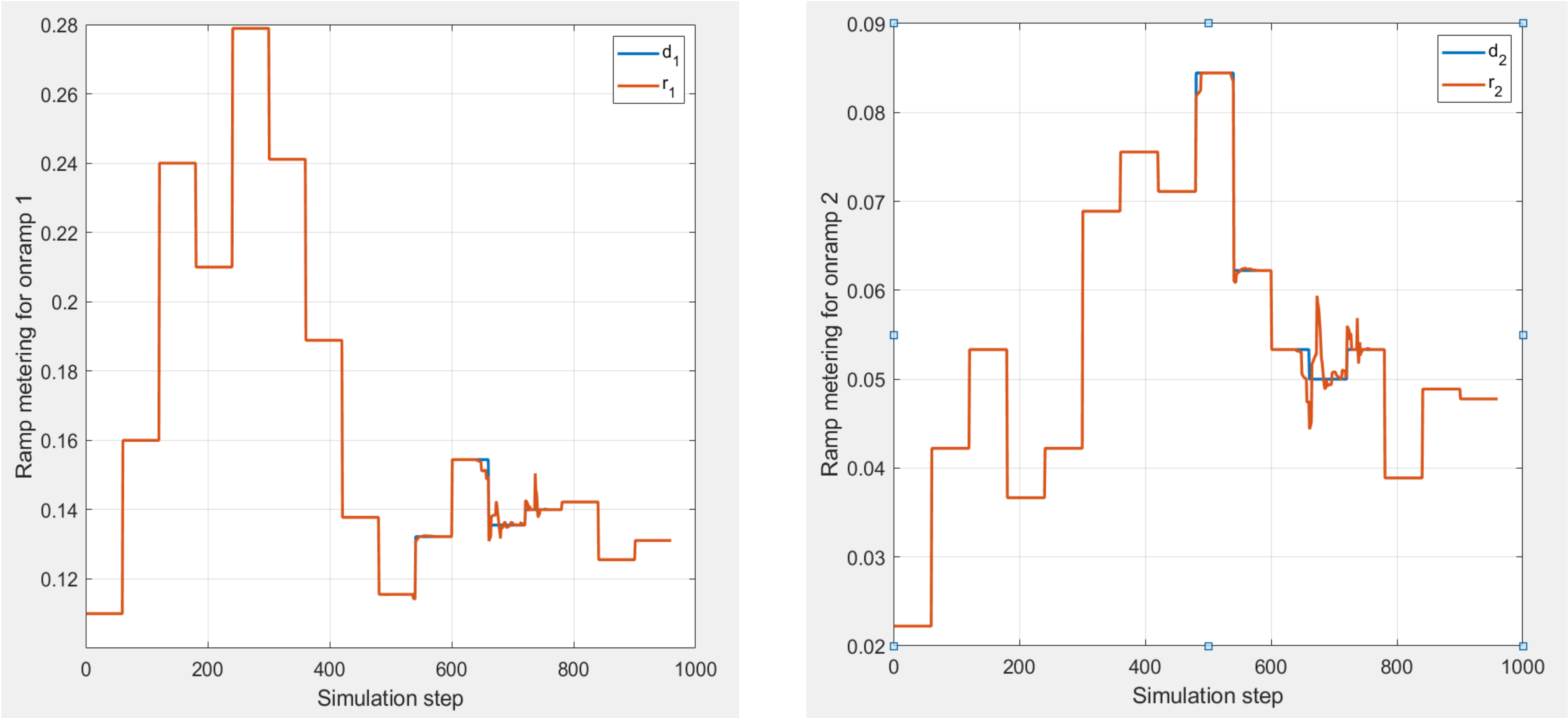
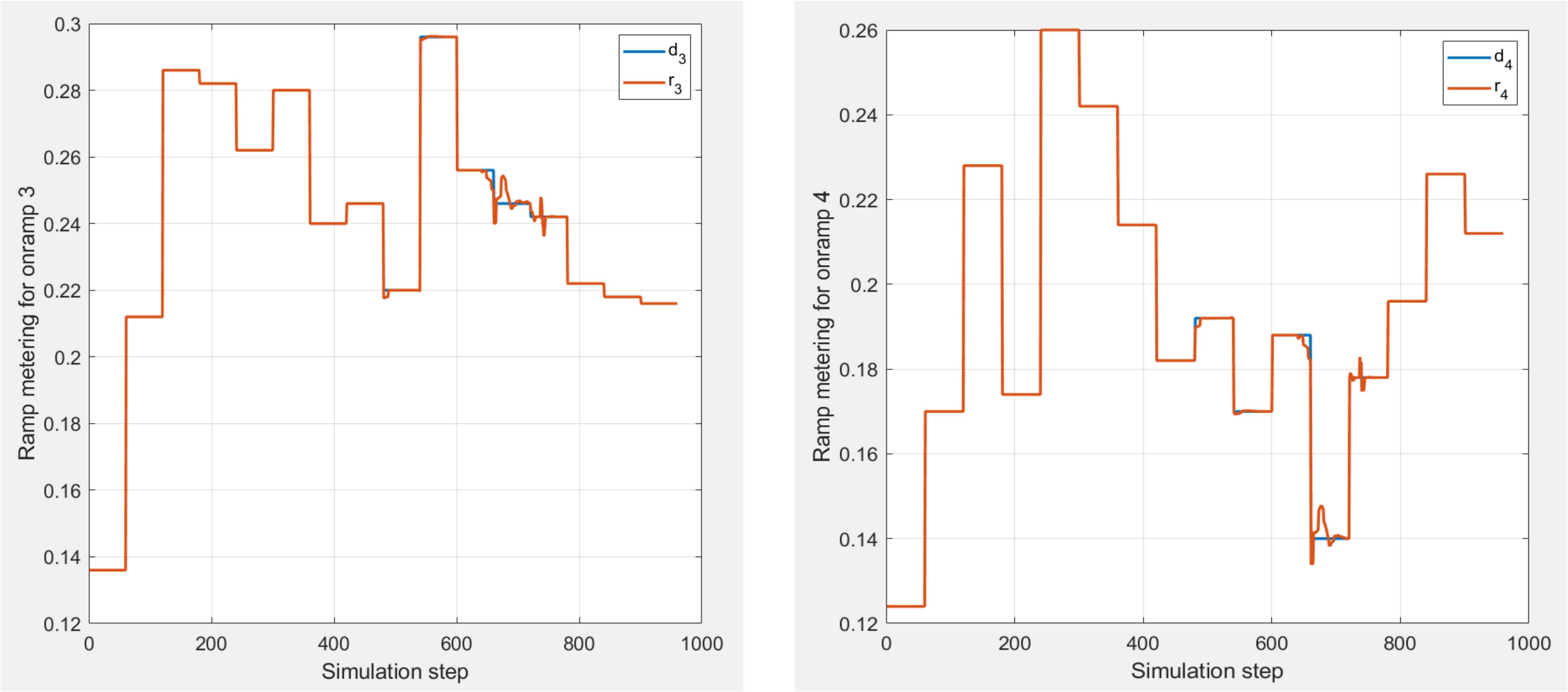
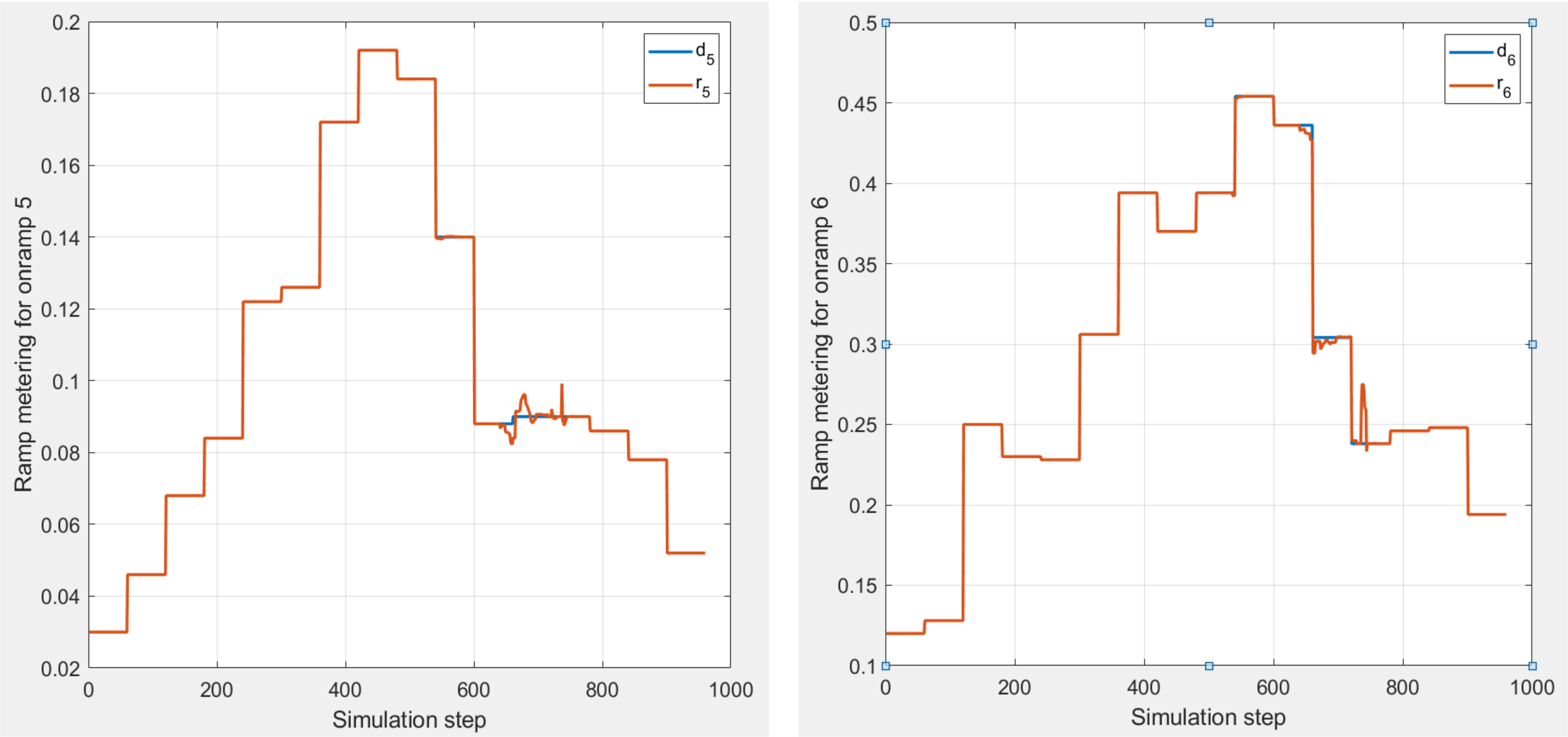


Figure 9



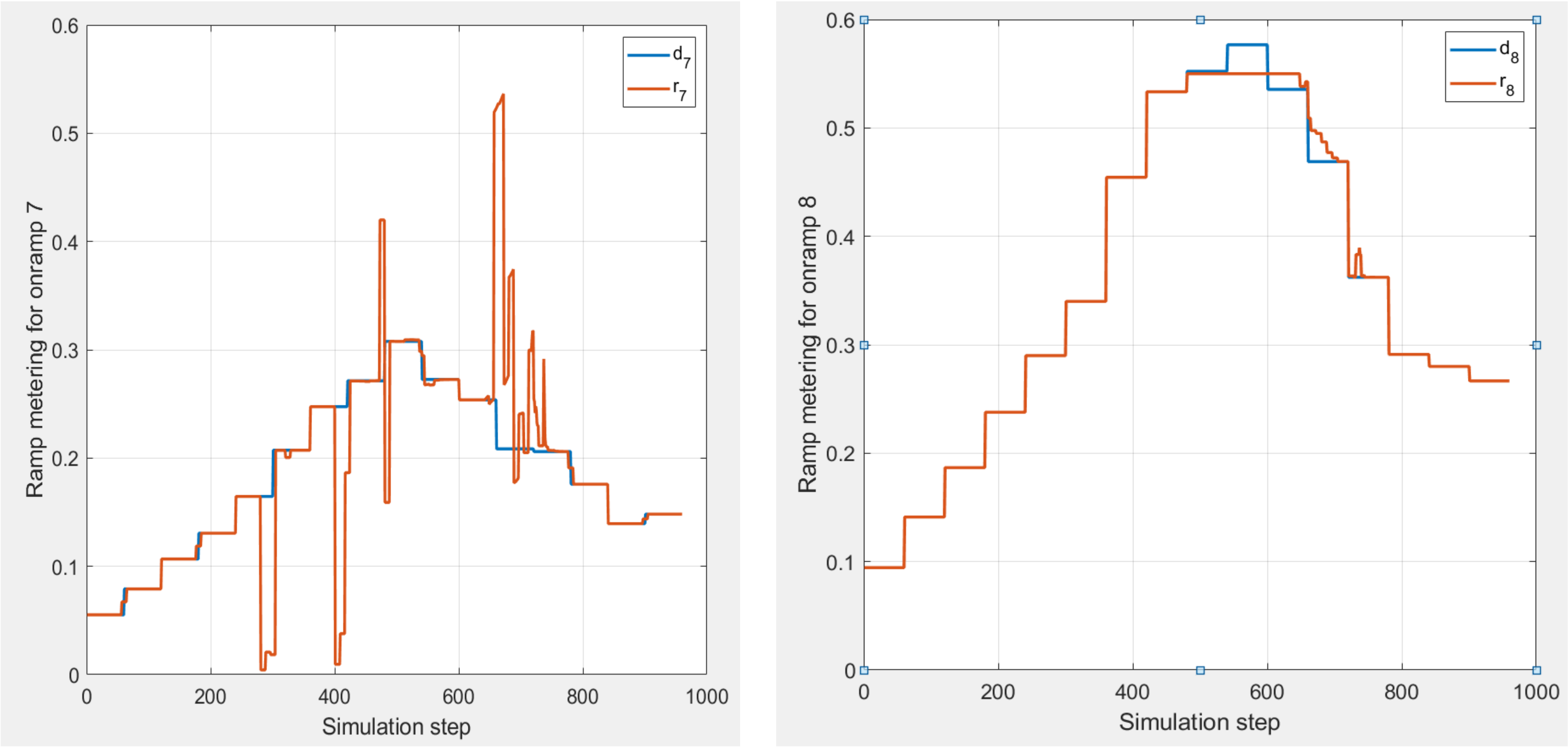
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0
200
400
600
800
1000
Ramp metering for onramp 3
Simulation step
d3
r3
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0
200
400
600
800
1000
Ramp metering for onramp 4
Simulation step
d4
r4

Figure 10



Ramp metering for onramp 5
Simulation step
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
200
400
600
800
1000
d_5
r_5
Ramp metering for onramp 6
Simulation step
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
d_6
r_6

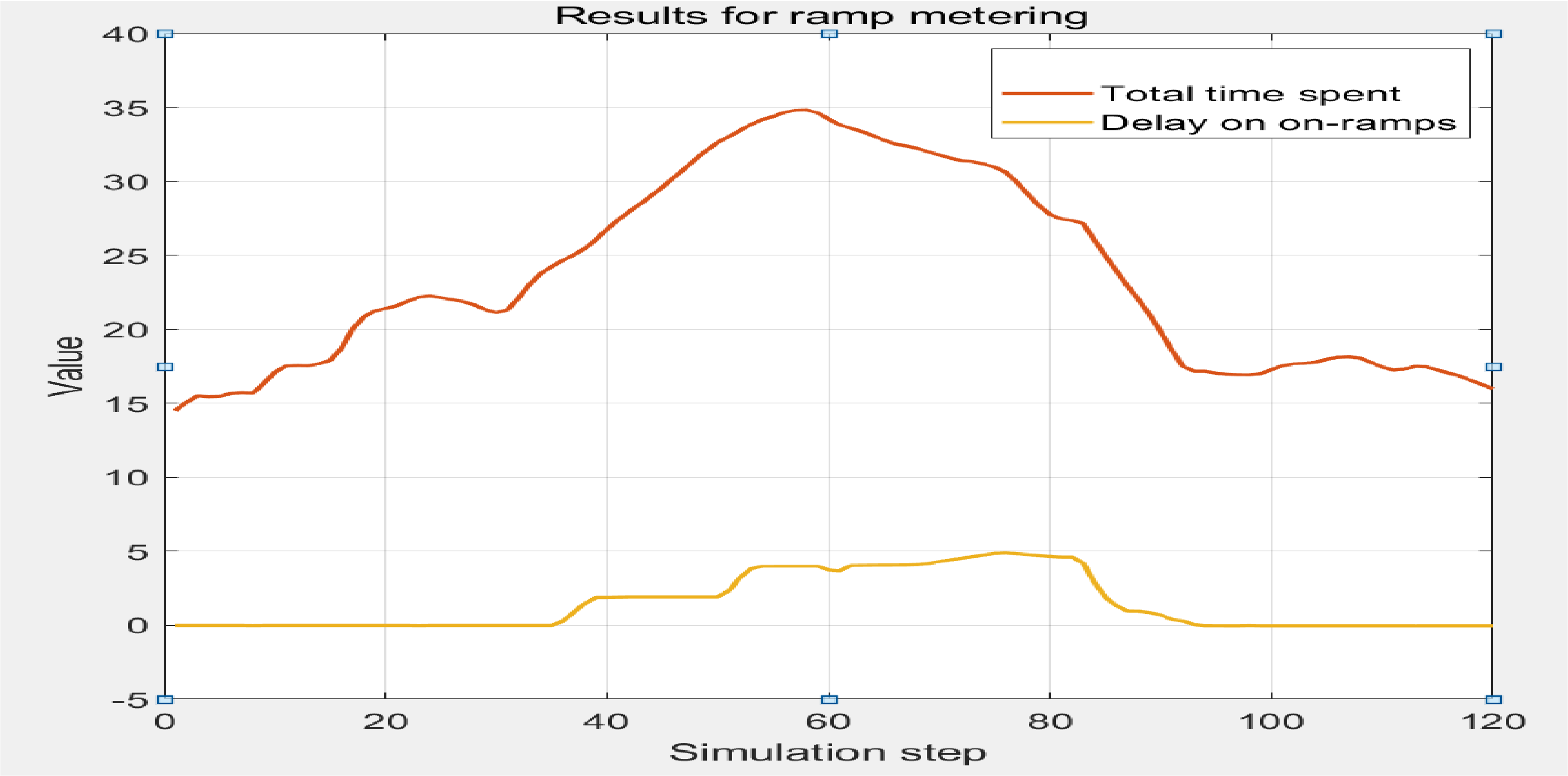
Figure 11



0.6
0.5
0.4
0.3
0.2
0.1
0
Ramp metering for onramp 7
0
200
400
600
800
1000
Simulation step
d_7
r_7
Ramp metering for onramp 8
Simulation step
d_8
r_8

Figure 12

Results of Total time Spent:



Name of model	Total time spent	Ramp delay	Percentage of reduction
No control	3617.3096h	0h	0%
RM	2842.2126h	173.4522h	21.4274%

Figure 13

Model with capacity drop for ramp metering and variable speed limit:

$$
\begin{aligned}
(\mathrm{DP})\min_{c} Z \;=\; & \sum_{t=1}^{N_p-1}\sum_{i=1}^{I}(\rho_{i,t}\Delta L_i \Delta T + q_{i,t}\Delta T) + \lambda_r \sum_{t=2}^{N_p-1}\sum_{i=1}^{I}(r_{i,t}-r_{i,t-1})^2 \\
& + \lambda_{bt}\sum_{t=2}^{N_p-1}\sum_{i=1}^{I}(b_{i,t}-b_{i,t-1})^2 + \lambda_{bs}\sum_{t=1}^{N_p-1}\sum_{i=2}^{I}(b_{i,t}-b_{i-1,t})^2
\end{aligned}
$$

Total Time Spent (TTS)

the time-variations of the on-ramp flows

the time and space variations of VSL rates $b_{i,t}$

s.t

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

$$f_{i,t} = \min\{f_{i,t}^{D}, f_{i+1,t}^{S} - \theta r_{i+1,t}\}$$

$$f_{i,t}^{D} = \min\left\{v_{f,i}\rho_{i,t},\ \left[Q_i + \alpha Q_i\left(\frac{\rho_{i,t} - \rho_{cr,i}}{\rho_{cr,i} - \rho_{max,i}}\right)\right]\right\}$$

$$f_{i+1,t}^{S} = \min\{Q_{i+1}, w_{i+1}(\rho_{max,i+1} - \rho_{i+1,t})\}$$

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

$$0 \le q_{i,t} \le q_{max,i}$$

$$0 \le r_{i,t} \le r_{max,i}$$

$$\left.\begin{aligned} v_{f,i}[b_{i,t}] &= v_{f,i} b_{i,t} \\ \rho_{cr,i}[b_{i,t}] &= \frac{\rho_{\max,i}\rho_{cr,i}}{b_{i,t}\rho_{\max,i} + (1-b_{i,t})\rho_{cr,i}} \end{aligned}\right\} \text{model 1}$$

2. Microscopic simulation with VSL and RM based on traffic date & ALINEA – HERO algorithm

The road Network System

Figure 14

RM & VSL control

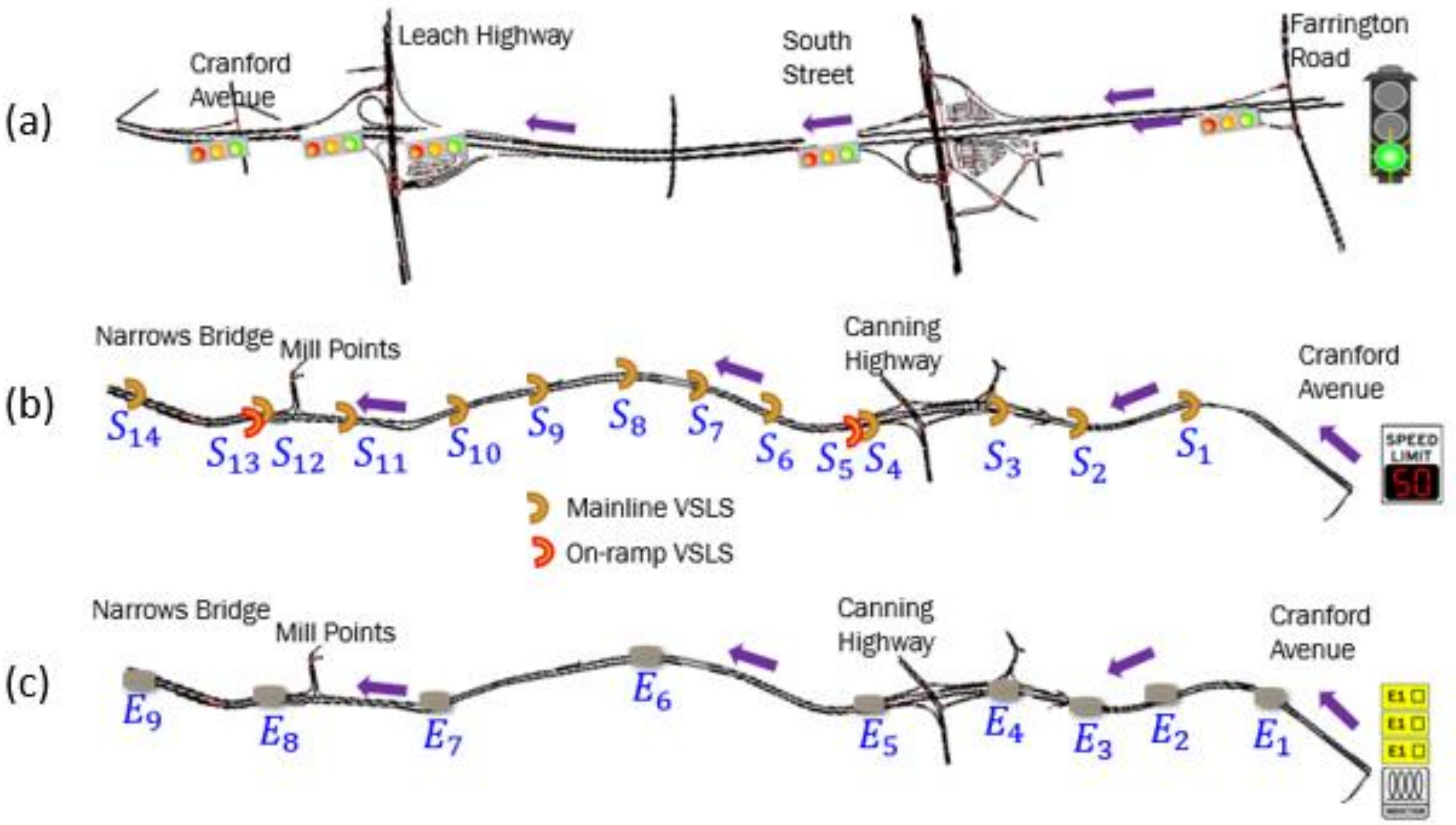


Figure 15

Table 1.

Edge	From	To	Length	lanes	RM/VSL	VDS	Remarks
1	J1	H622	540.62	3		0091, 0200	
2	H622	J2	150.74	4	RM	0090	Farrinton RD.
3	J2	H618	226.09	4		0190	
4	H618	J4	215.70	4			
5	J4	J5	398.23	3			
6	J5	H617	389.89	3		0089	
7	H617	J7	268.88	5	RM		South St.
8	J7	J8	146.65	4		0180, 0700	
9	J8	H559	590.53	4			
10	H559	H558	587.50	3		0170, 0702	Leach Hwy SB
11	H558	J11	230.21	4	RM		
12	J11	H554	211.05	3		0160	
13	H554	J13	123.91	4	RM		Leach Hwy NB
14	J13	H553	189.17	3		0088,0150	
15	H553	J15	227.38	4	RM		Cranford AV.
16	J15	J16	48.68	3			
17	J16	J17	685.48	3			
18	J17	J18	1435.18	3	VSL	0087, 0140, 0086	
19	J18	H551	293.21	3			
20	H551	H547	545.83	3	VSL	0130	
21	H547	J21	127.12	4			Canning SB Man.
22	J21	J22	128.3	3		0085	
23	J22	J23	273.33	3			
24	J23	J24	37.84	4			
25	J24	H549	130.44	3		0084	
26	H549	J26	134.99	4	VSL	0120	Canning NB
27	J26	J27	79.65	4	VSL		
28	J27	J28	3170.18	3	VSL	0003, 0083,0100,0082	
29	J28	J29	148.32	3	VSL		
30	J29	H500	370.6	4	VSL	0081	
31	H500	J31	119.89	4	VSL		Mill Pts
32	J31	H503	259.97	4	VSL		
33	H503	J33	239.04	5		0080	
34	J33	J34	363.95	5			

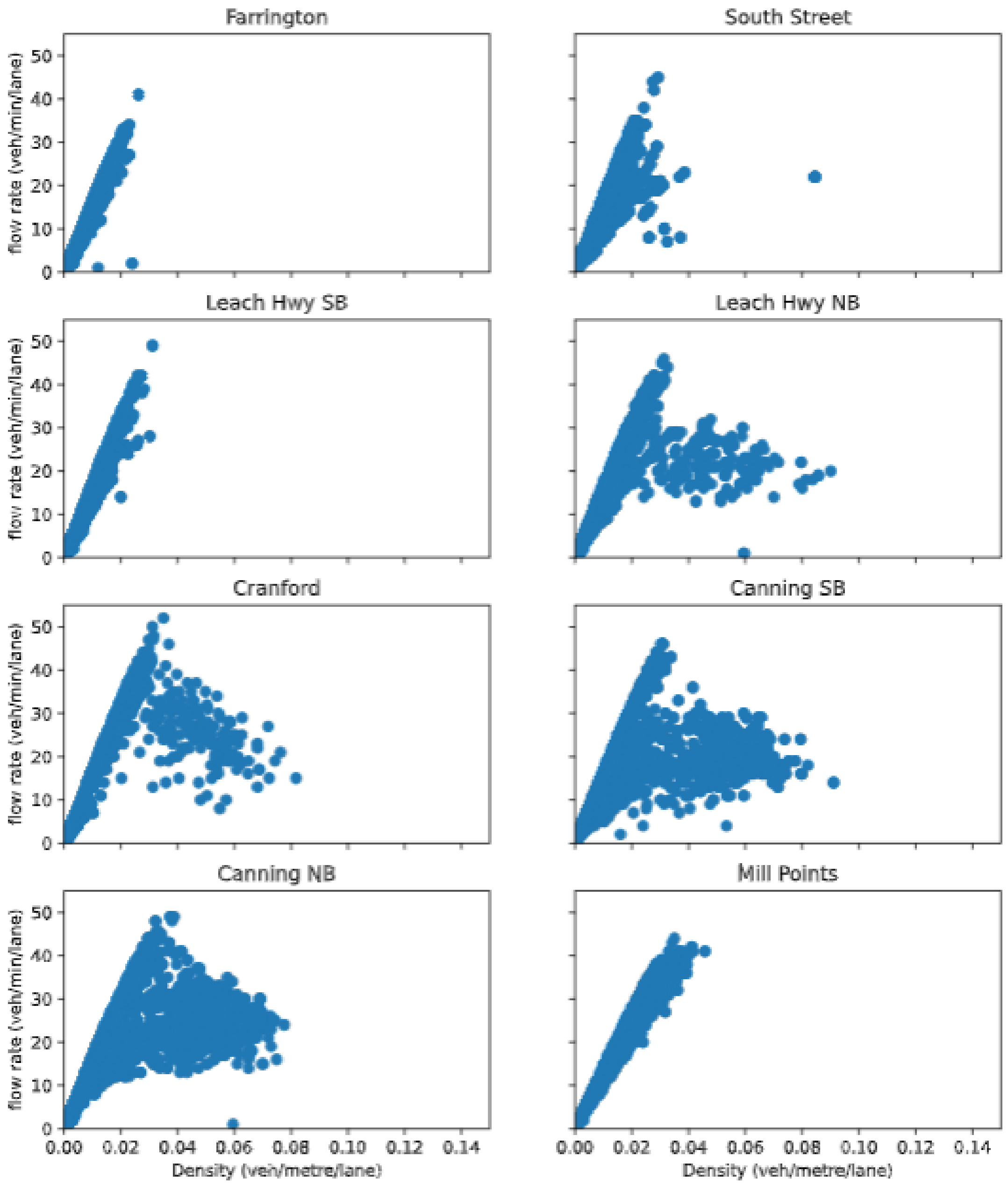


Figure 16

The Farrington on-ramp

The South on-ramp

The Leach SB on-ramp

The Leach NB on-ramp

The Cranford Av. on-ramp

A non-linear constrained optimization problem

$$\min \sum_{k=1}^{K} \sum_{j=1}^{D} \left(\hat{s}_j(k) - s_j(k)\right)^2 \quad \text{with } \hat{s}_j(k) = \sum_{i=1}^{O} r_i(k) p_{ij}; \tag{1}$$

subject to, for some i in all possible OD pairs,

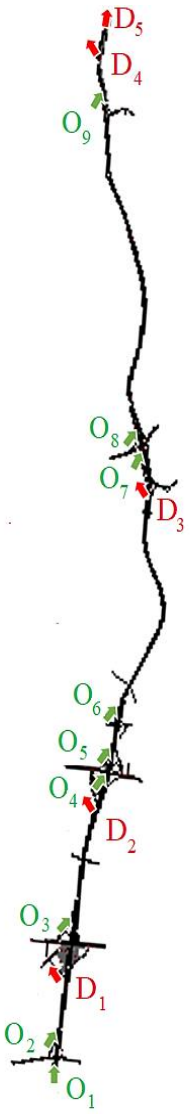
$$\begin{cases} r_i(k) = \max\{r_i^{LC}(k),\ r_i^m(k,m,\lambda)\} \left(1 - \mathrm{rand}(0,1)\frac{\mathrm{R}}{\mathrm{C}}\delta_{RM,k}\right) \leq \lambda_i[k] + \frac{1}{\Delta t} m_i[k]; & (2) \\ m_i(k) = m_i(k-1) + \Delta t(\lambda_i(k-1) - r_i(k-1)) \leq m_{max,i}; & (3) \\ \sum_{j=1}^{D} p_{ij} = 1, & (4) \end{cases}$$

where $r_i^m(k,m,\lambda)$ and $r_i^{LC}(k)$ are given by

$$r_i^m(k,m,\lambda) = \frac{1}{T_c}\left(m_i(k) - m_{max,i}\right) + \lambda_i(k-1); \tag{5}$$

$$r_i^{LC}(k) = r_i^{LC}(k-1) - K_p(\rho^d(k) - \rho^d(k-1)) + K_R(\rho_{cr} - \rho(k)). \tag{6}$$

On-ramp Demand, $\lambda_i[k]$



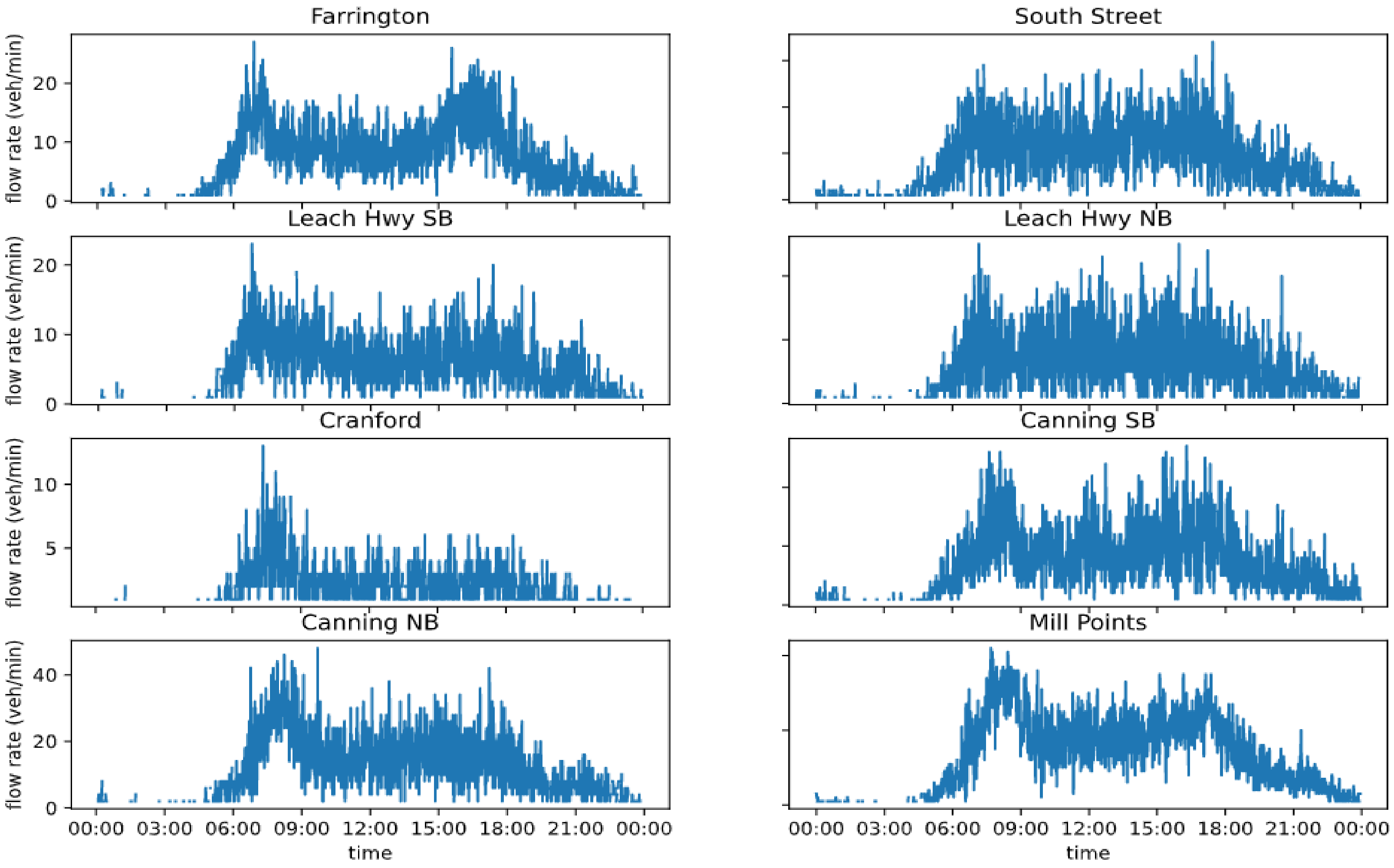
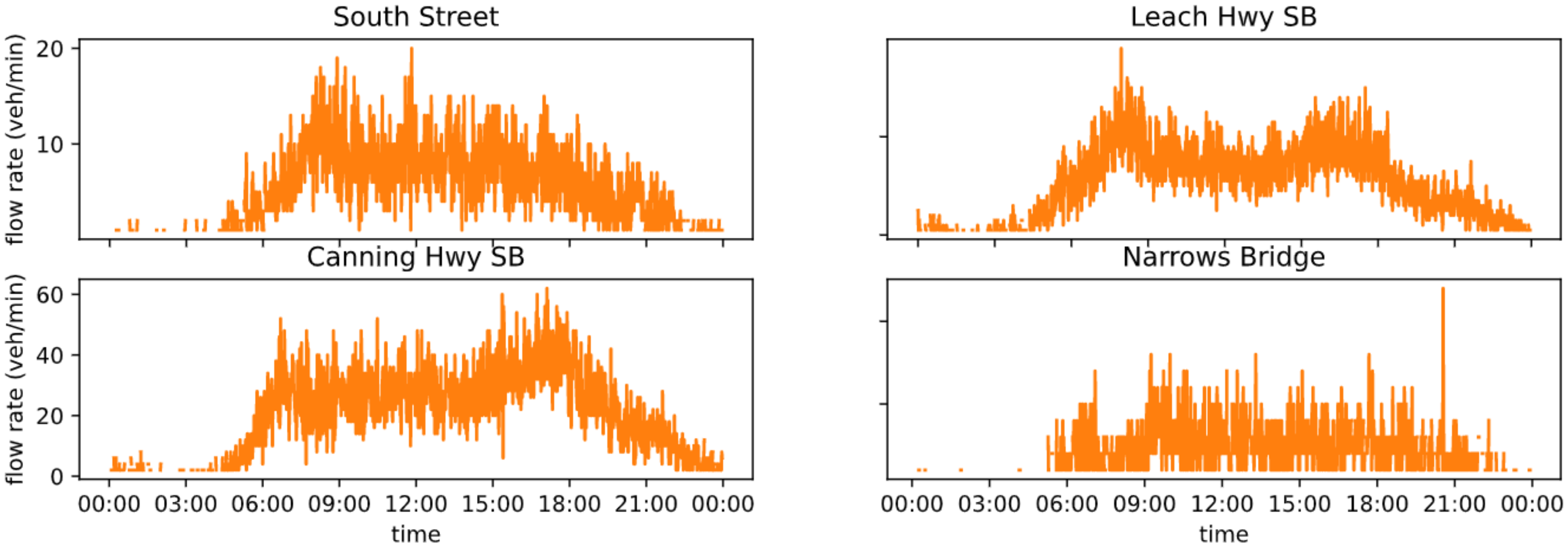


Figure 17

Off-ramp outgoing flow, $s_j(k)$



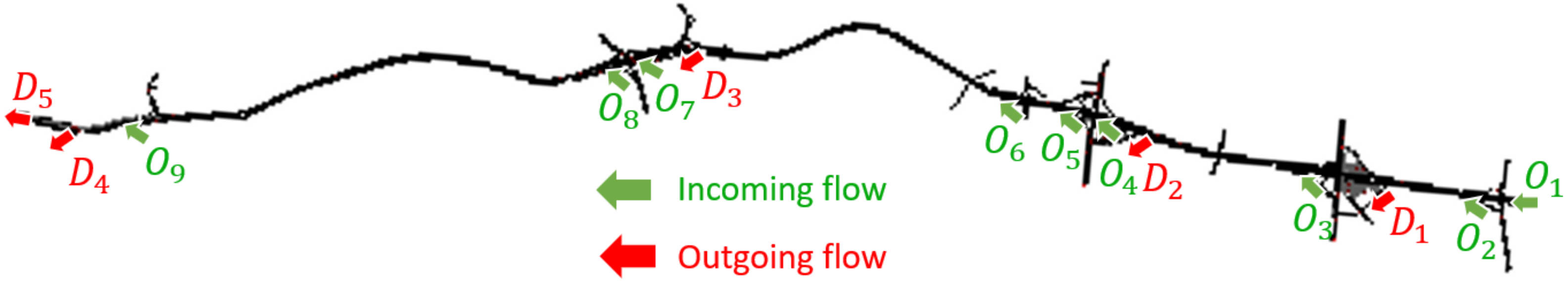


Figure 18

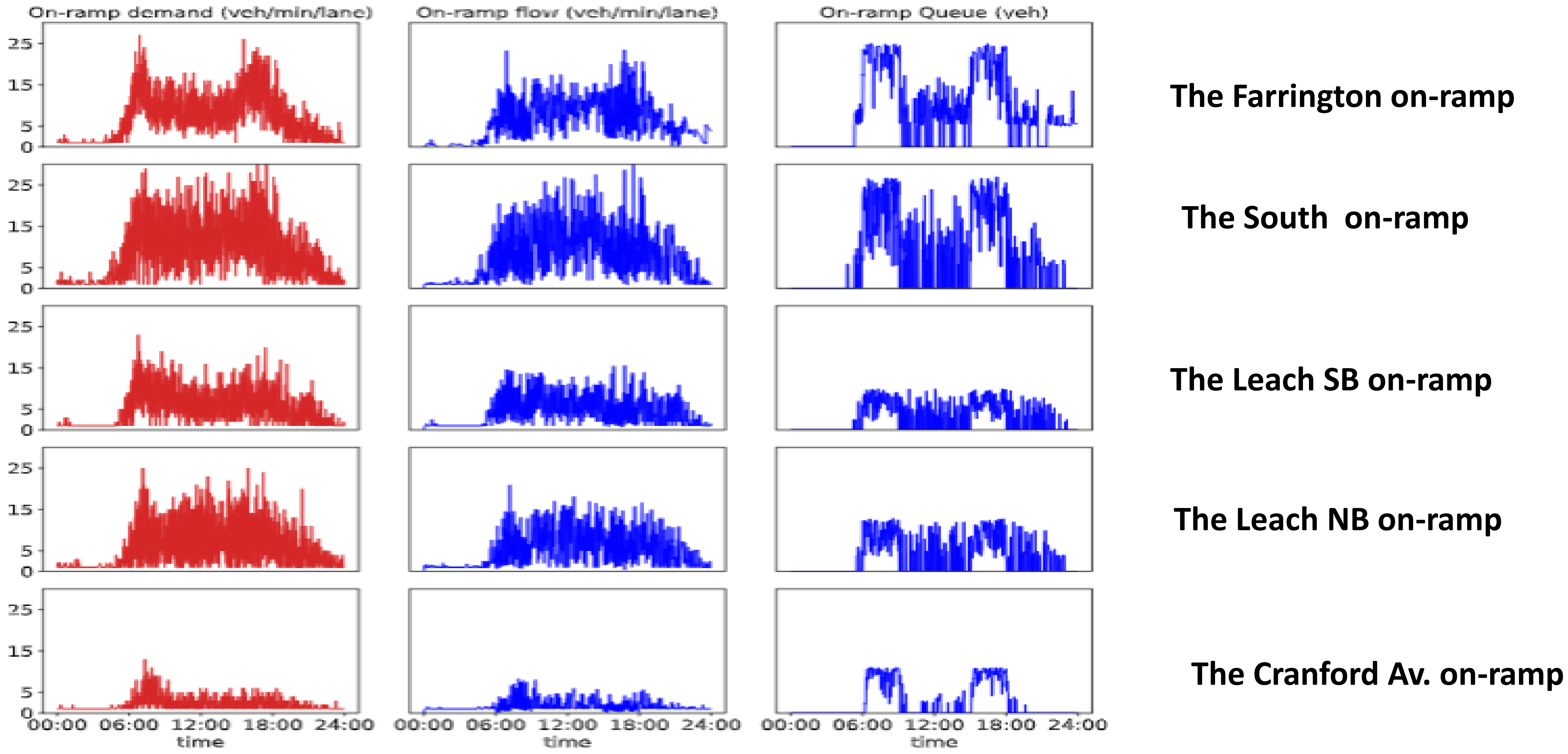
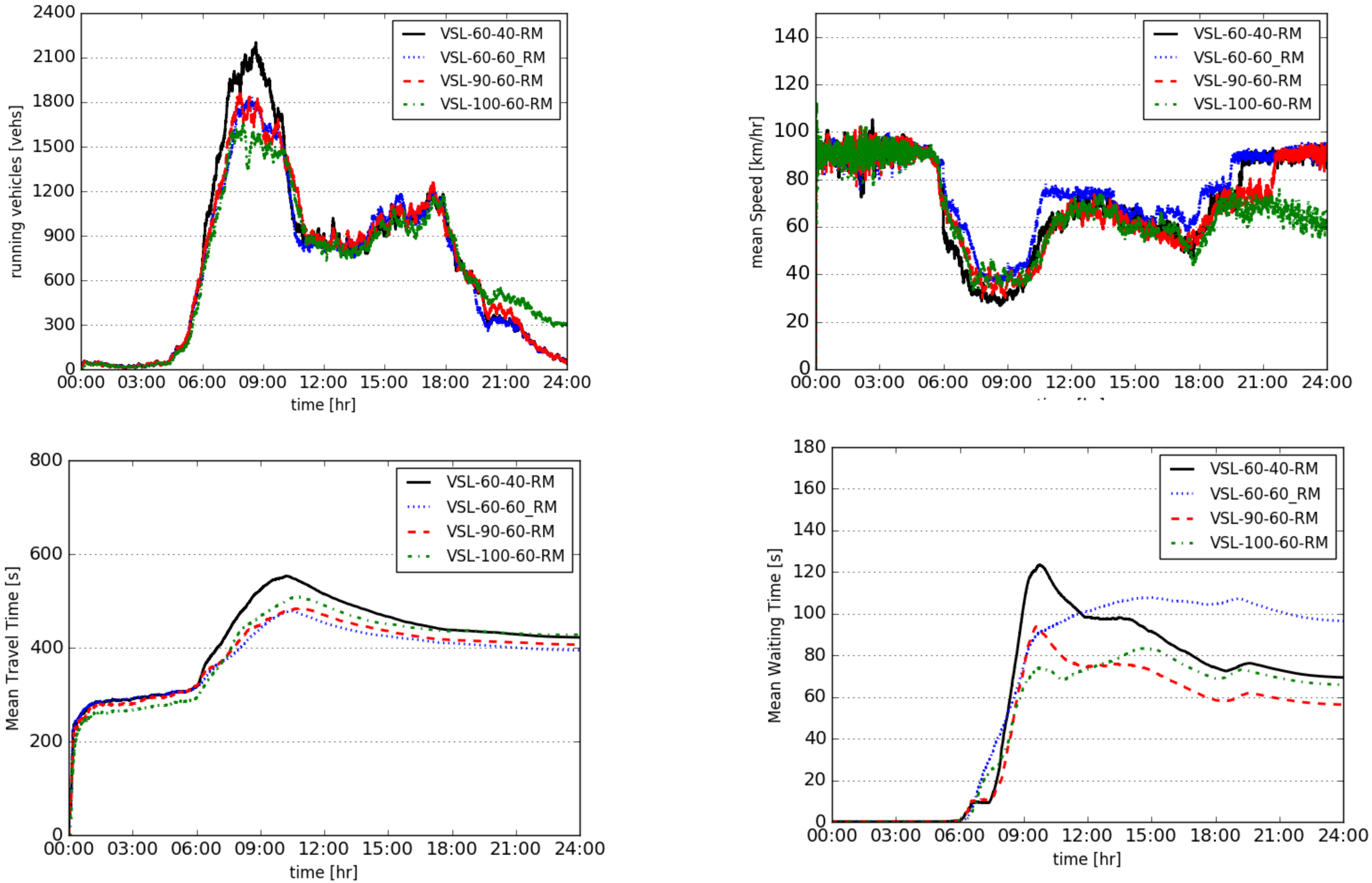

On-ramp demand (veh/min/lane)
On-ramp flow (veh/min/lane)
On-ramp Queue (veh)
25
15
5
0
00:00 06:00 12:00 18:00 24:00
time
The Farrington on-ramp
The South on-ramp
The Leach SB on-ramp
The Leach NB on-ramp
The Cranford Av. on-ramp

Figure 19

The proportion of trip from the ith original (origin) flowing to the jth destination (sink)

- Table 2.

Route	D_1	D_2	D_3	D_4	D_5
O_1	0.048	0.072	0.016	0.000	0.864
O_2	0.273	0.199	0.141	0.088	0.3
O_3		0.328	0.197	0.144	0.331
O_4			0.277	0.263	0.460
O_5			0.294	0.284	0.422
O_6			0.287	0.298	0.415
O_7				0.283	0.717
O_8				0.271	0.729
O_9				0.082	0.918



VSL-60-40-RM
VSL-60-60_RM
VSL-90-60-RM
VSL-100-60-RM
running vehicles [vehs]
time [hr]
mean Speed [km/hr]
Mean Travel Time [s]
Mean Waiting Time [s]

Figure 20

3. Further data analysis: traffic prediction

by Convolutional Neural Network & Long-short Term Memory

Sequence modelling

- one-to-one:
  one input, one output
- one-to many:
  one input, variable outputs
- many-to one:
  variable inputs, one output
- many-to-many:

Kwinana Freeway Network

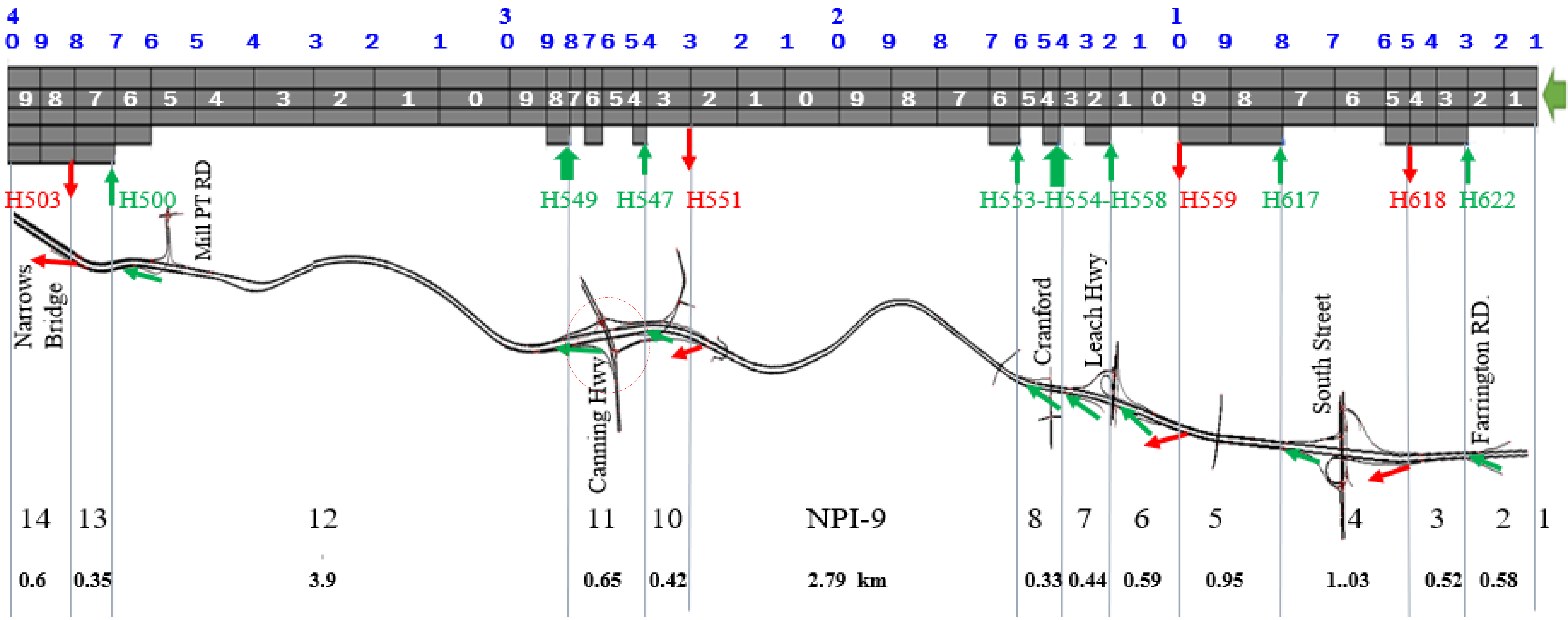
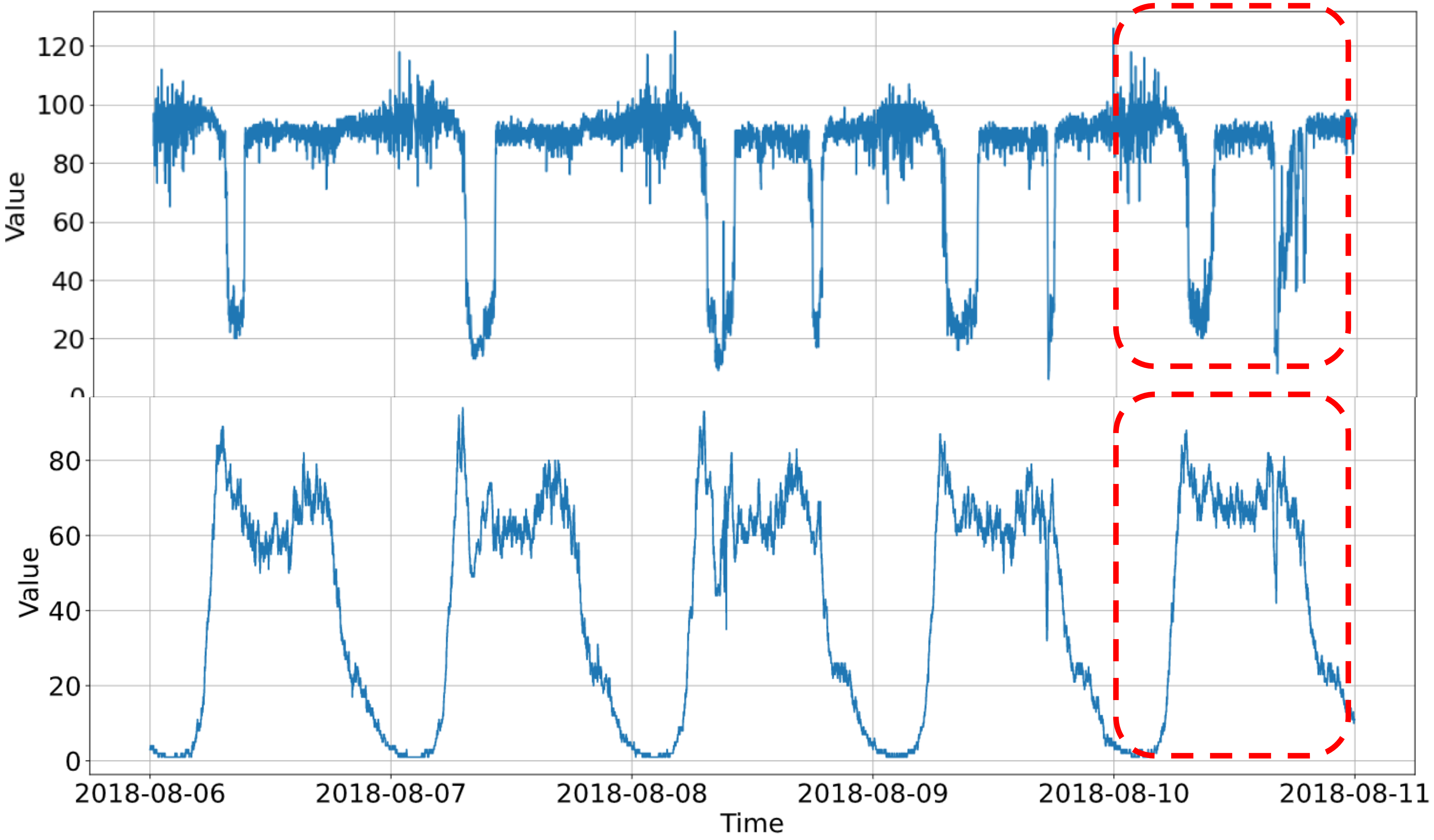


Figure 21



120
100
80
60
40
20
0
Value
80
60
40
20
0
Value
2018-08-06
2018-08-07
2018-08-08
2018-08-09
2018-08-10
2018-08-11
Time

Figure 22

Parameter Setting

- Split time = 5728
- Window size = 60 # Number of slices to create from the time series
- Batch size = 256
- Shuffle buffer size = 1000
- Forecast period = 30
  # For splitting data in many-to-many sequence model

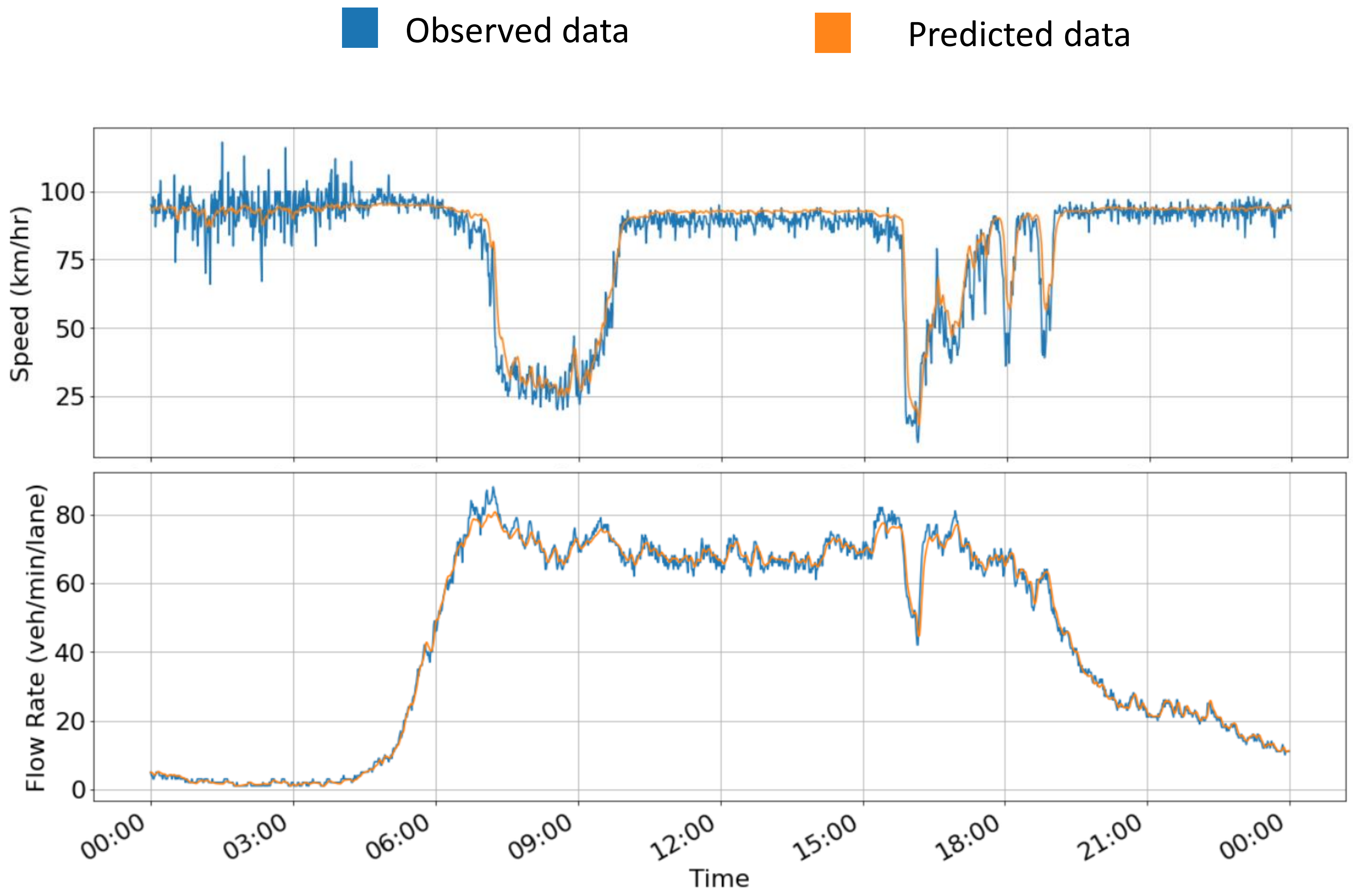

Observed data
Predicted data
Speed (km/hr)
100
75
50
25
Flow Rate (veh/min/lane)
80
60
40
20
0
00:00
03:00
06:00
09:00
12:00
15:00
18:00
21:00
00:00
Time

Figure 23

huber function

```
tf.keras.losses.huber(y_true, y_pred, delta=1.0)
```

Computes Huber loss value.

For each value x in `error = y_true - y_pred`:

```
loss = 0.5 * x^2                  if |x| <= d
loss = 0.5 * d^2 + d * (|x| - d)  if |x| > d
```

where d is `delta`. See: https://en.wikipedia.org/wiki/Huber_loss

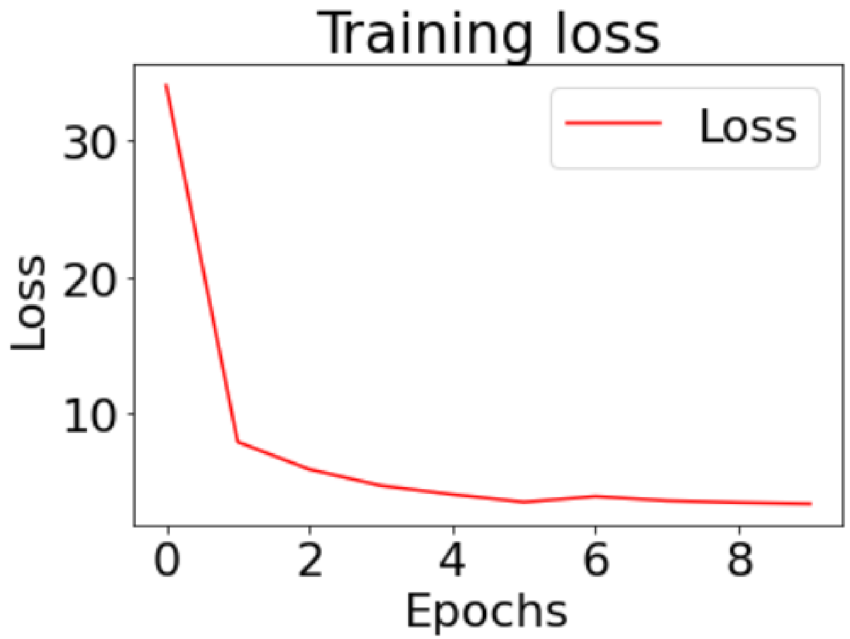
Arguments

- **y_true**: tensor of true targets.
- **y_pred**: tensor of predicted targets.
- **delta**: A float, the point where the Huber loss function changes from a quadratic to linear.

Returns

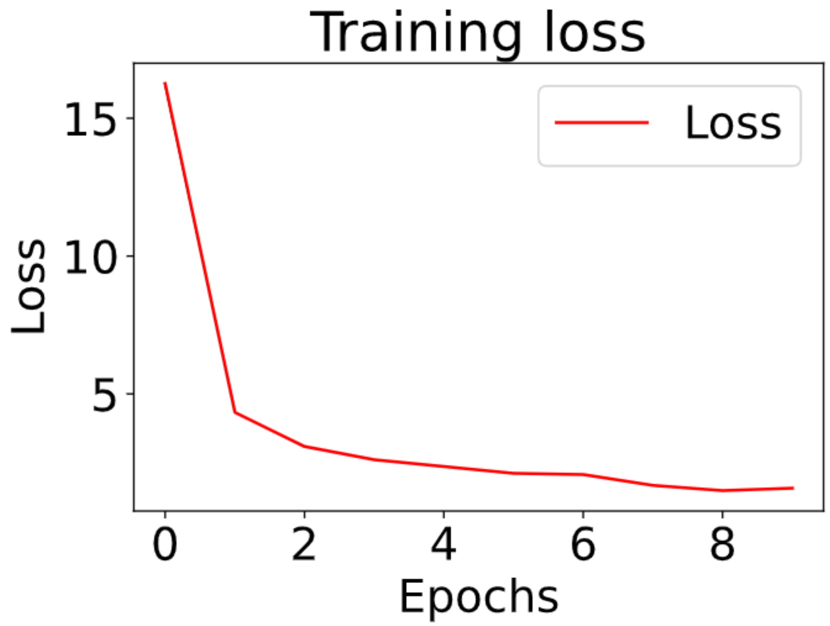
Tensor with one scalar loss entry per sample.

Training Loss function



Speed Prediction

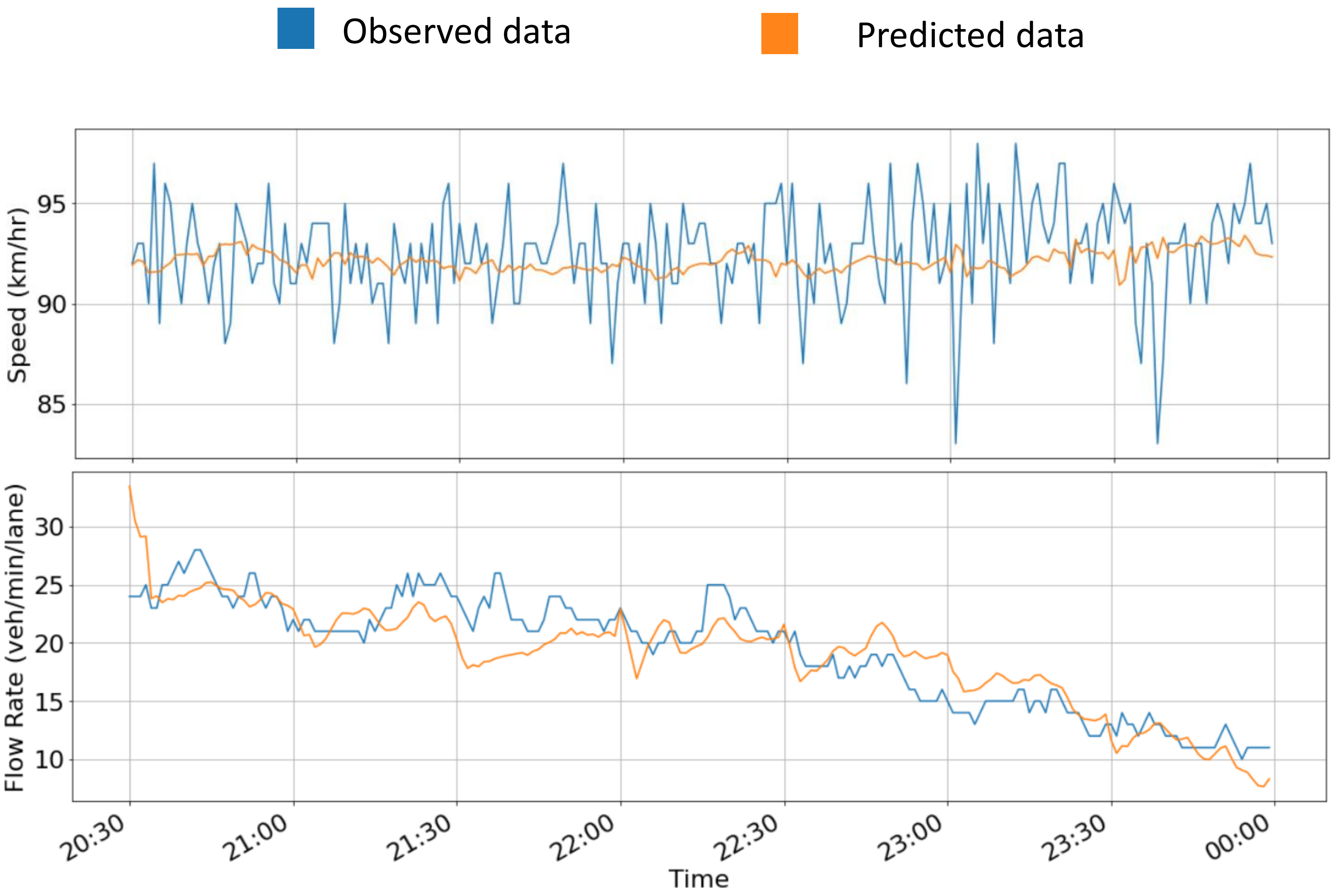
MAE = 4.25656



Flow rate Prediction

MAE = 1.3852582

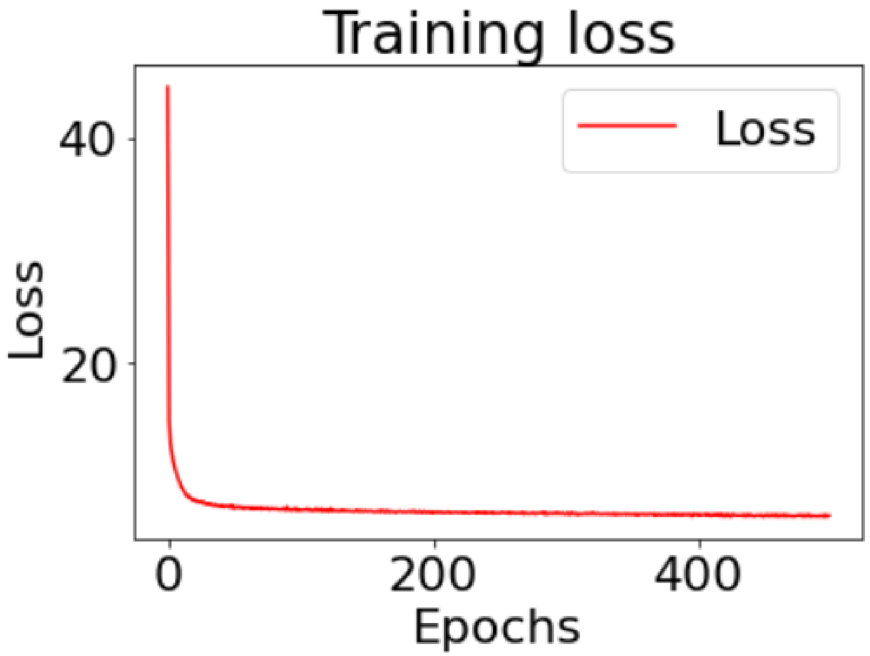
Figure 24



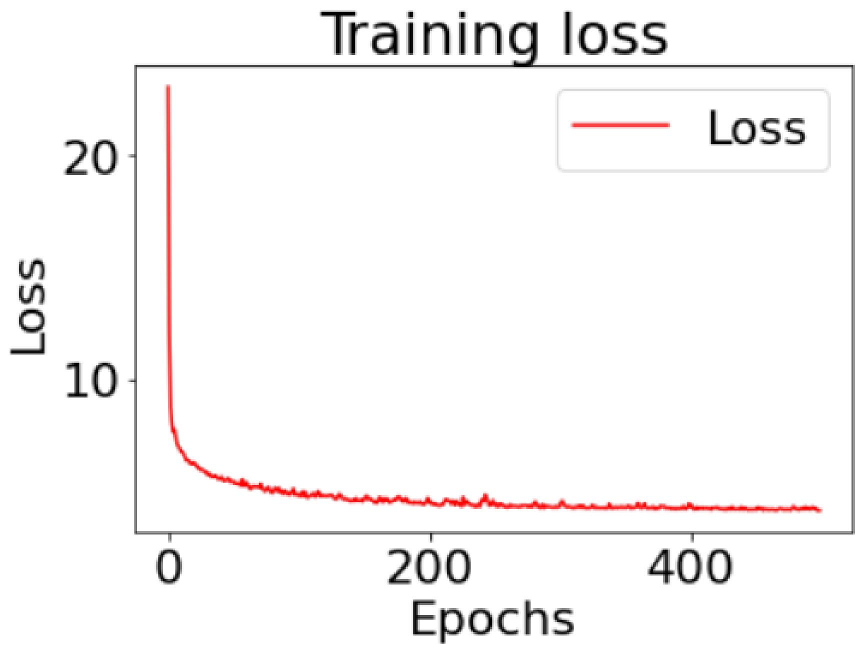
Observed data
Predicted data
Speed (km/hr)
95
90
85
Flow Rate (veh/min/lane)
30
25
20
15
10
20:30
21:00
21:30
22:00
22:30
23:00
23:30
00:00
Time

Figure 25

Training Loss function



Speed Prediction
MAE = 1.9975



Flow rate Prediction
MAE = 1.9215

Figure 26

NPI-11

Speed

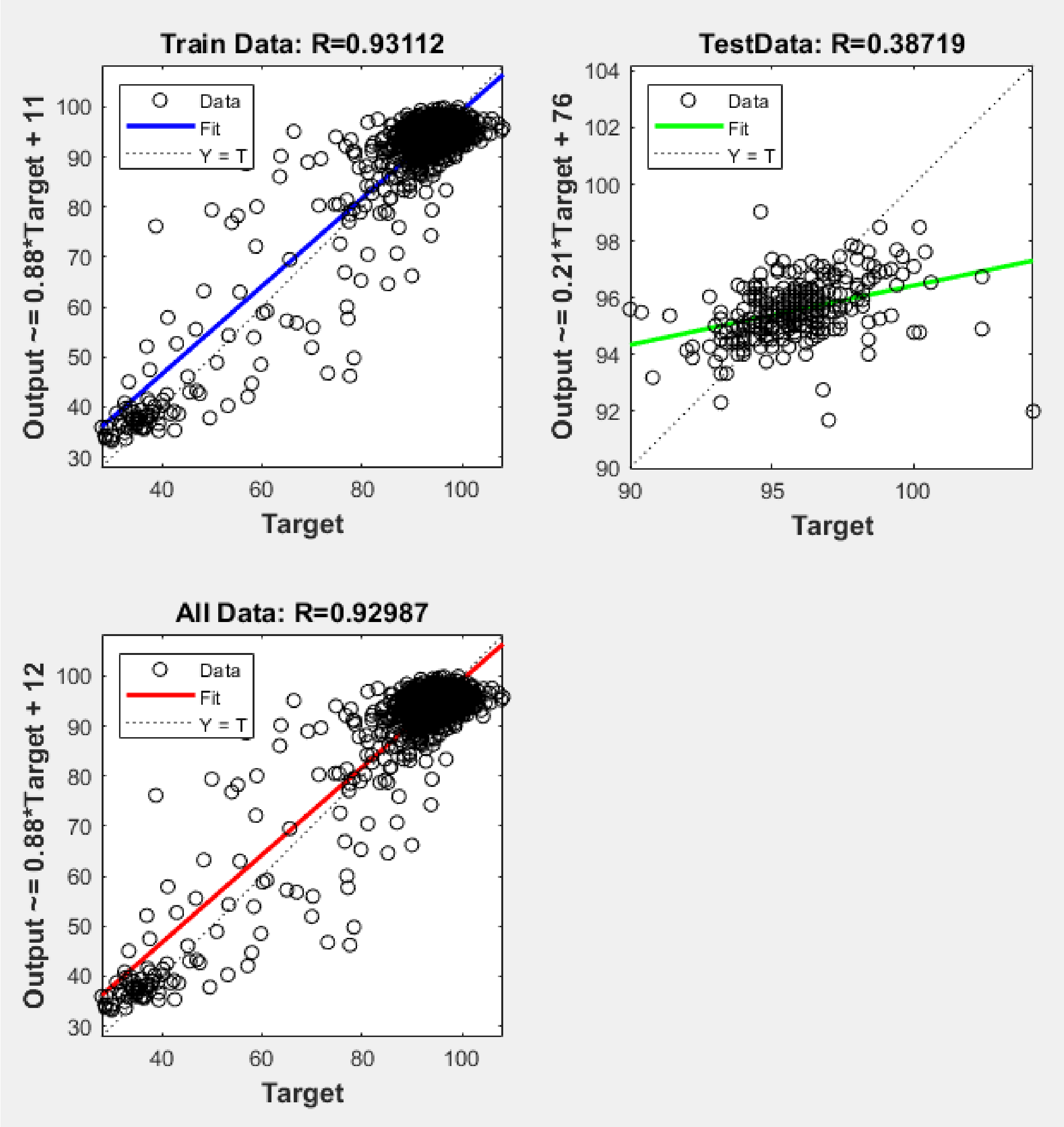


Figure 27

NPI-11

Flow rate

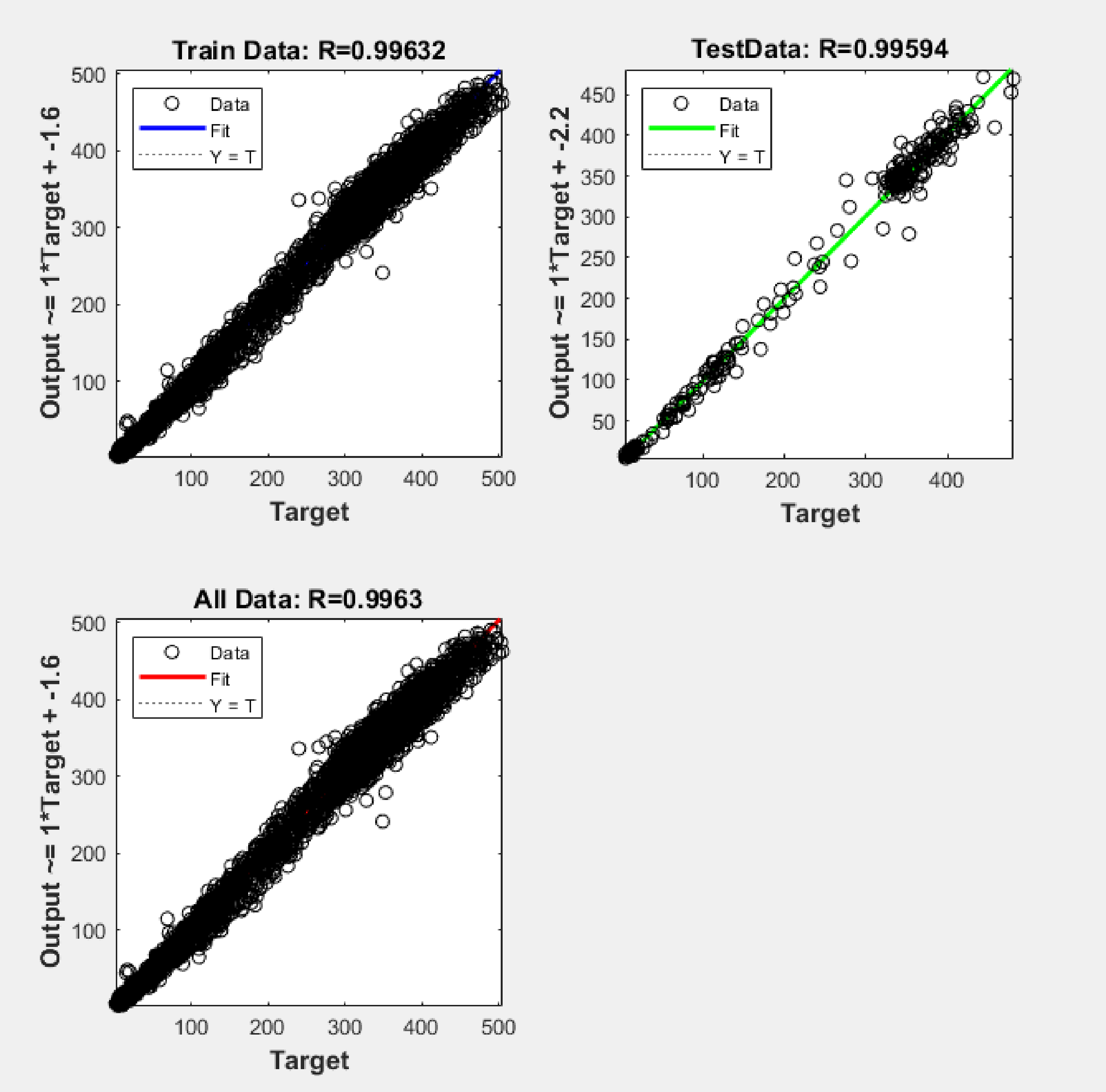


Figure 28

ACKNOWLEDGEMENTS

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THANK YOU
For Your Attention