On Simulation and Optimization of Freeway Network Operations

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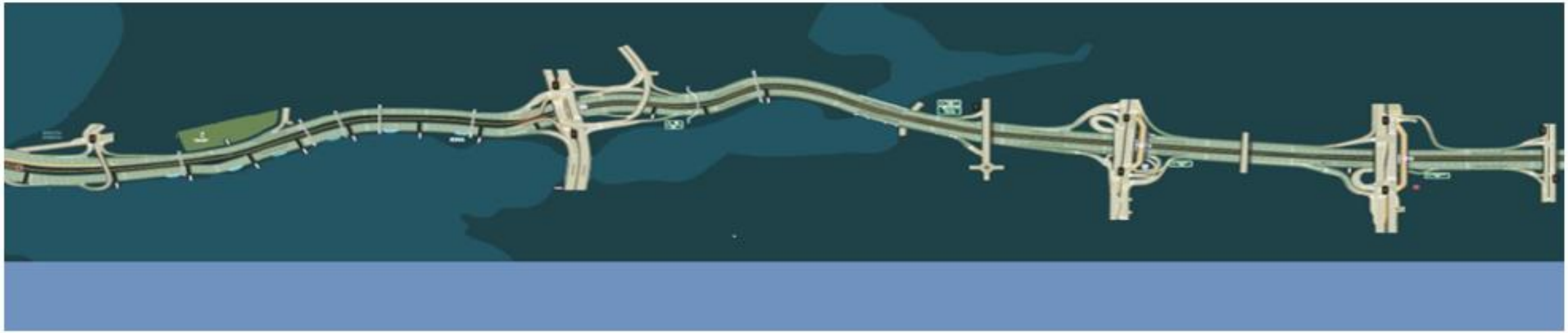
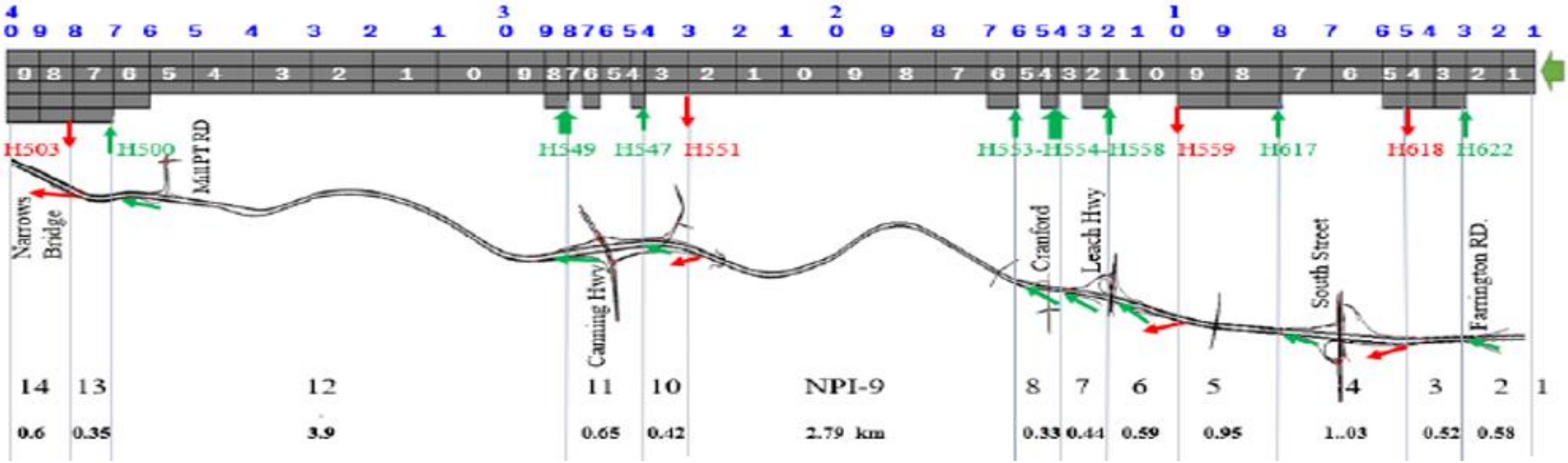
Progress from last PSG meeting

- Optimization of freeway traffic flow via VSL control
- Microscopic simulation with VSL and RM

- Control of congestion under normal and incident conditions through Ramp Metering via optimization and data analysis

Road Map (from Farrington Road to Narrows Bridge)



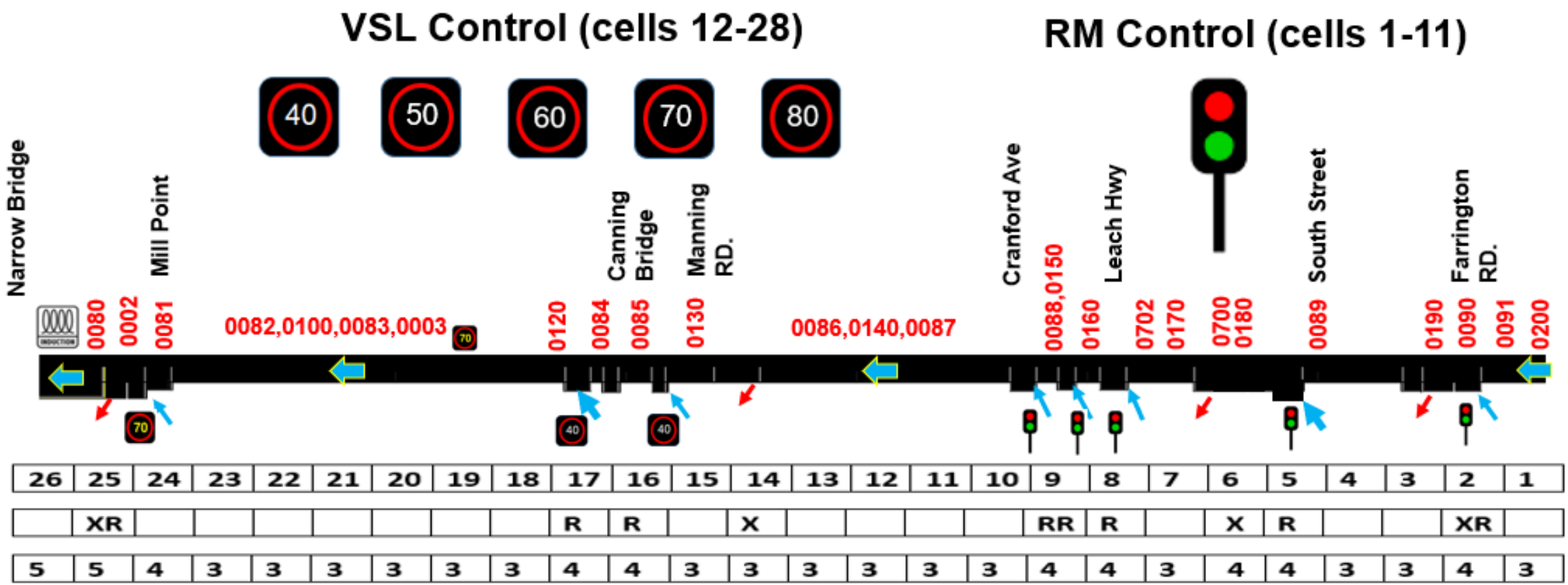


The Road Network Structure

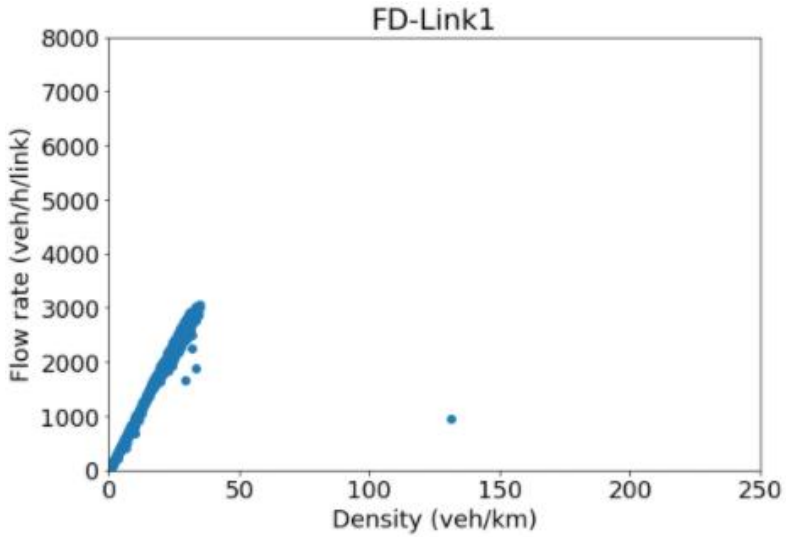
Road segments	From	To	Length	#Lane	VDS	CELL No.	Remark
1	Start	H622	382.72	3	0091, 0090	0	
2	H622	I2	230.55	4	0200	1	Farrington
3	I2	H618	276.55	4	0190		
4	H618	I4	172.35	4		2	
5	I4	I5	398.24	3			
6	I5	H617	467.39	3	0089	3	
7	H617	I7	206.48	5		4	South Street
8	I7	I8	146.66	4	0180		
9	I8	H559	590.47	4	0700	5	
10	H559	H558	587.38	3	0170	6	Leach Hwy & Cranfrod
11	H558	I11	230.15	4	0702	7	
12	I11	H554	211.56	3	0160		
13	H554	I13	146.91	4	0088	8	
14	I13	H553	190.46	3	0150		
15	H553	I15	226.08	4			
16	I15	I16	49.51	3	0087	9-13	
17	I16	I17	681.02	3	0140		
18	I17	I18	1437.04	3	0086		

Road segments	From	To	Length	#Lane	VDS	CELL No.	Remark
19	I18	H551	395.63	3		14	
20	H551	H547	417.96	3	0130		
21	H547	I21	123.64	4		15	Manning / Canning Bridge
22	I21	I22	128.30	3	0085		
23	I22	I23	162.52	3			
24	I23	I24	125.5	4			
25	I24	H549	112.63	3	0084	16	
26	H549	I26	137.79	4			
27	I26	I27	79.78	4	0120		
28	I27	I28	3165.58	3	0003;0083; 0100;0082	17-22	
29	I28	I29	273.65	3		23	
30	I29	H500	245.59	4	0081		
31	H500	I31	128.76	4		24	
32	I31	H503	219.17	4	0002		
33	H503	I33	243.22	5	0080	25	
34	I33	END	408.85	5			

Computational Domain



VDS DATA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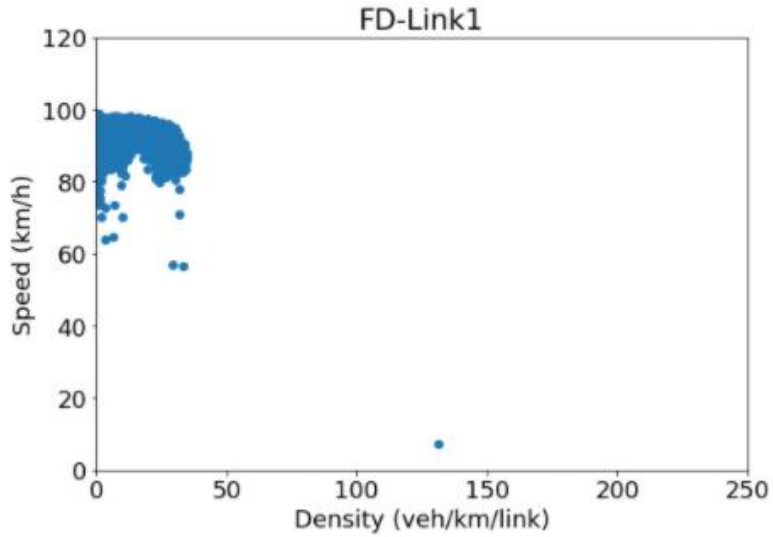
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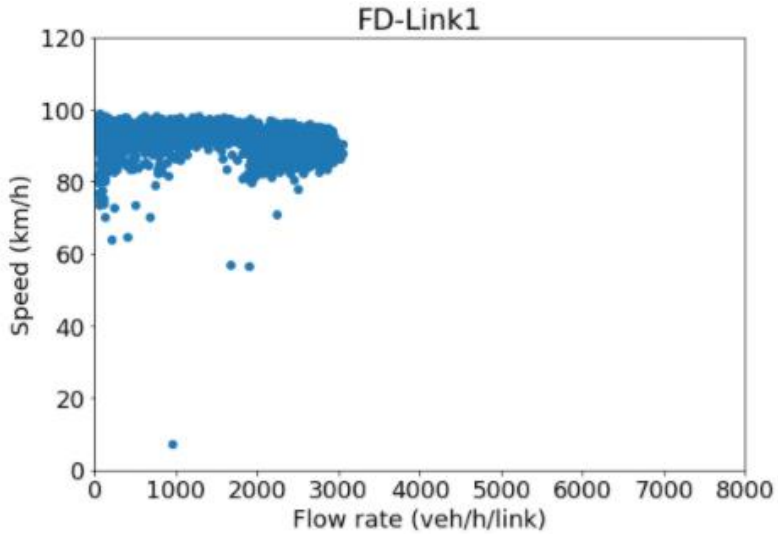
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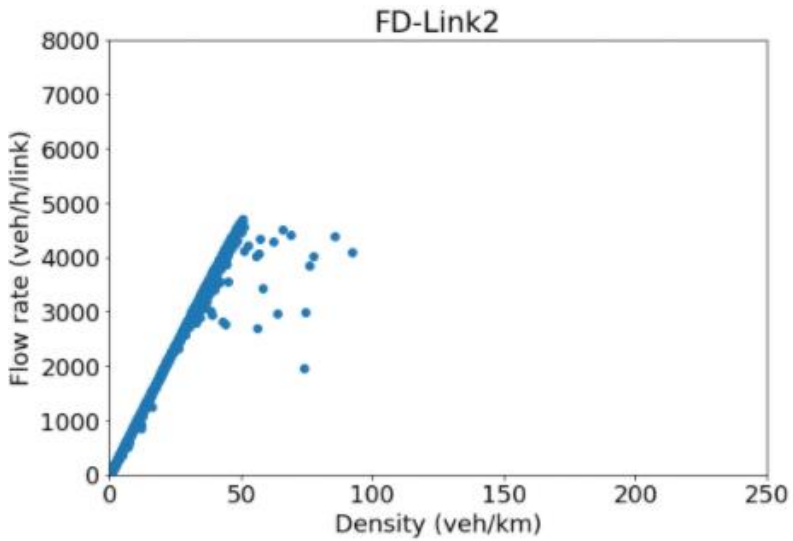
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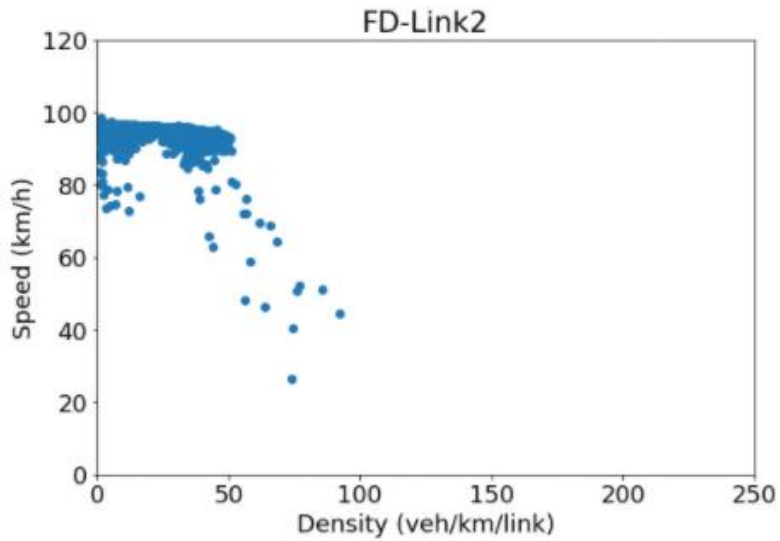
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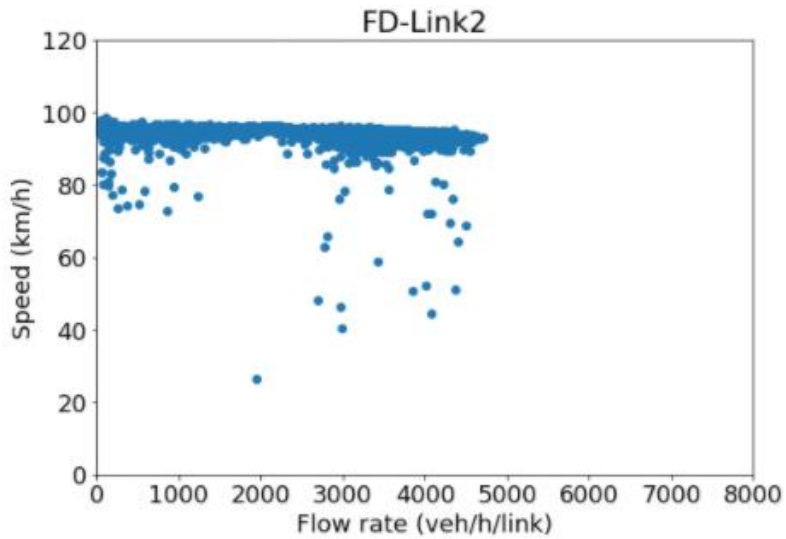
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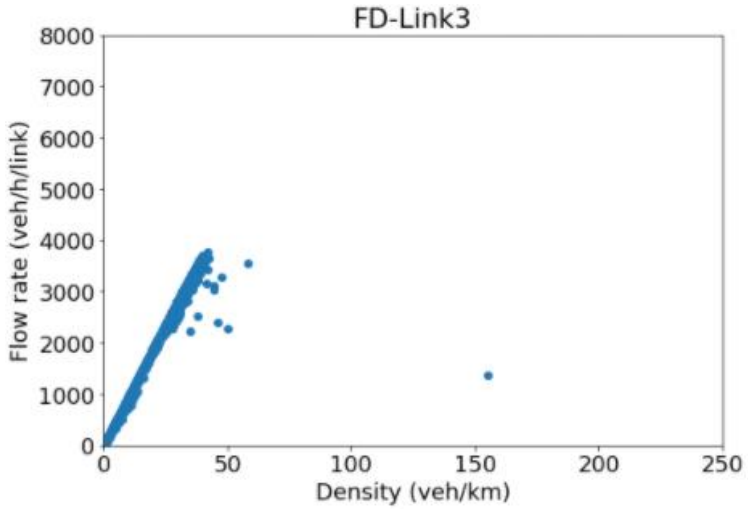
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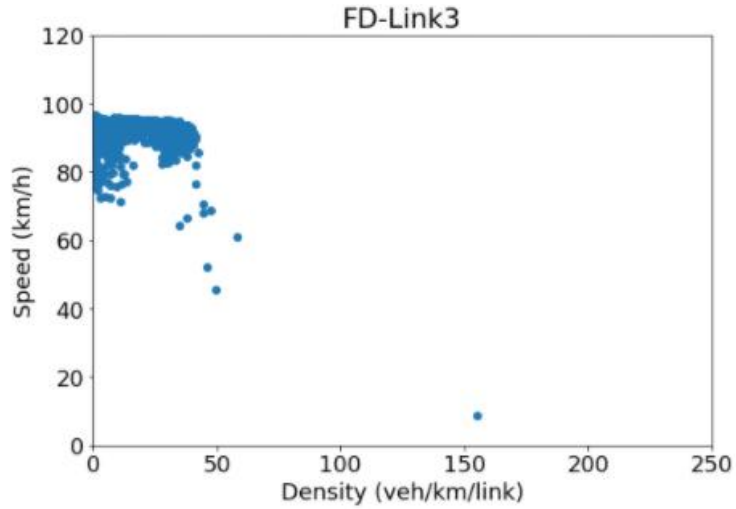
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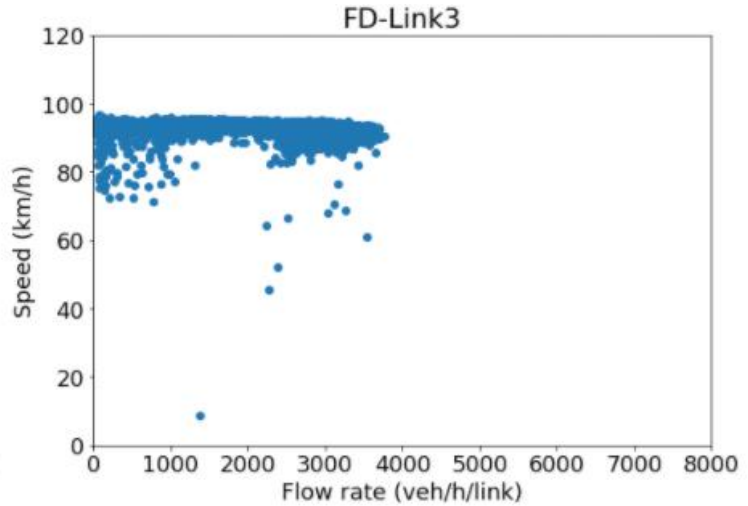
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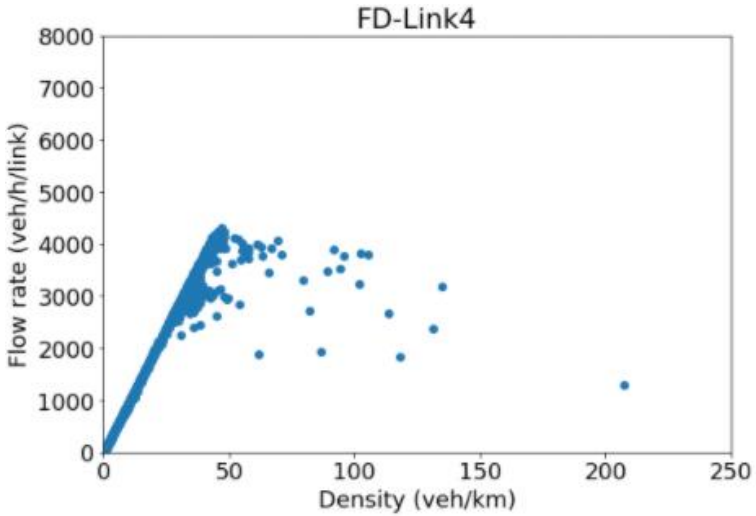
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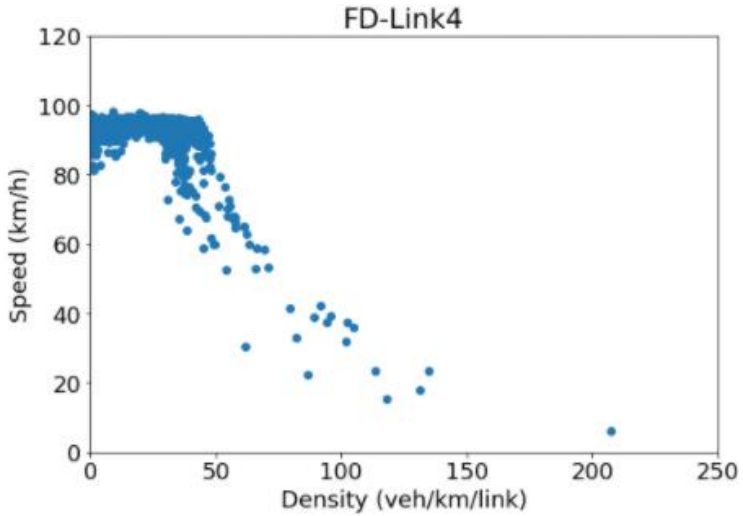
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Density (veh/km/link)
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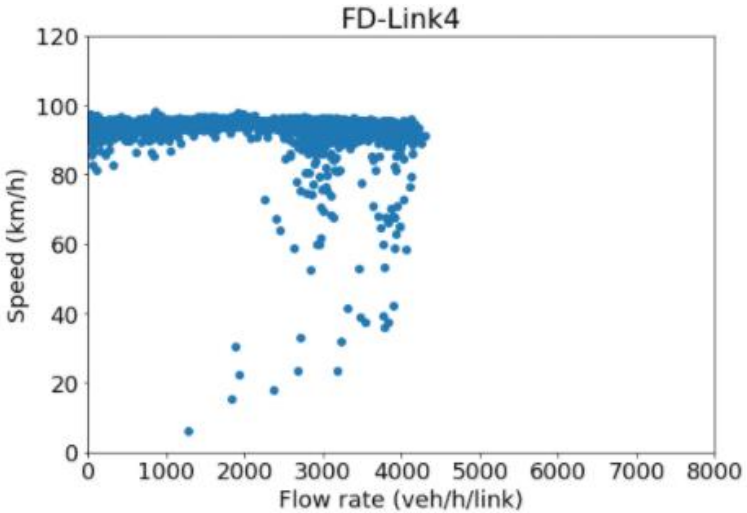
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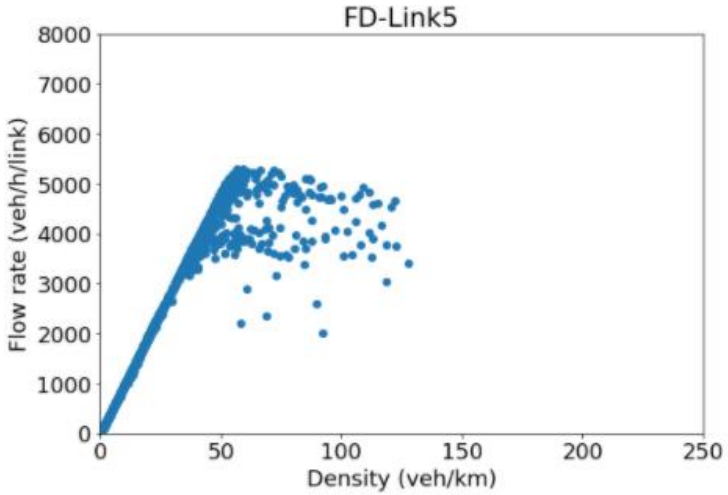
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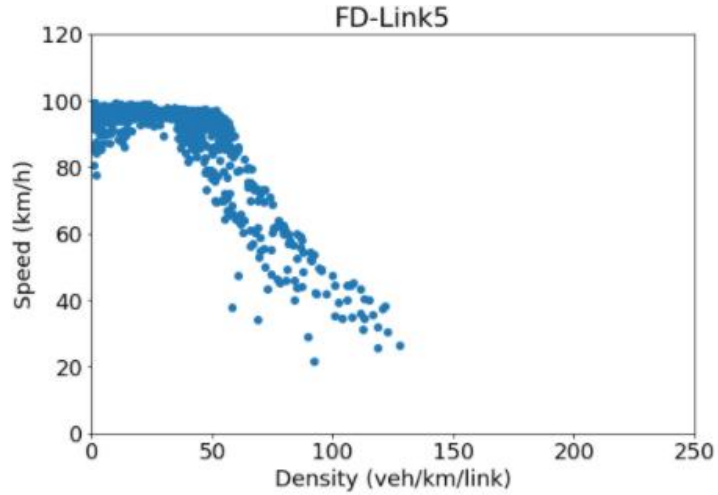
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Density (veh/km/link)
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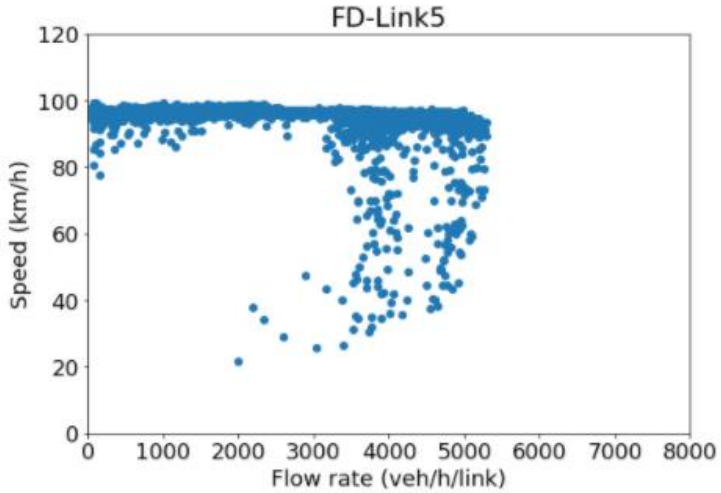
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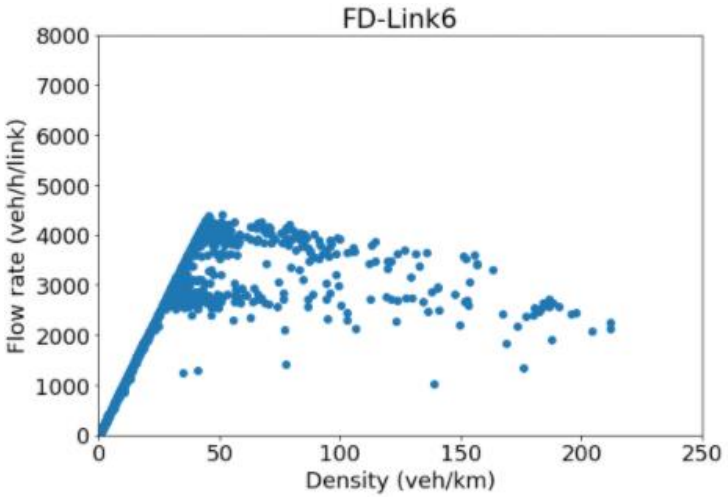
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Density (veh/km)
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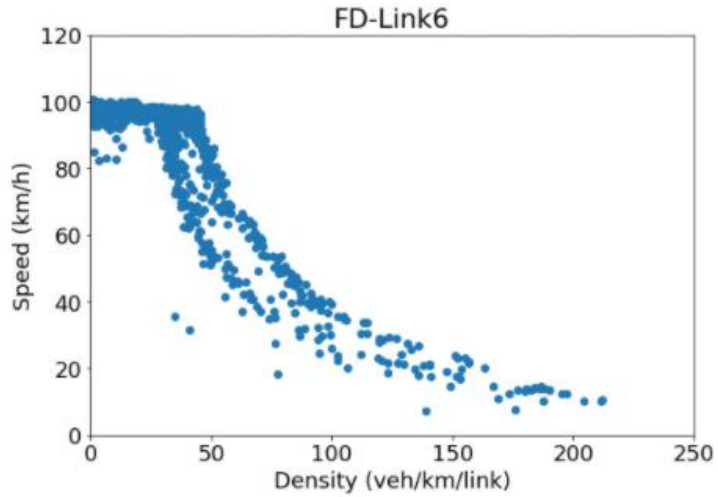
FD-Link6
Speed (km/h)
Density (veh/km/link)
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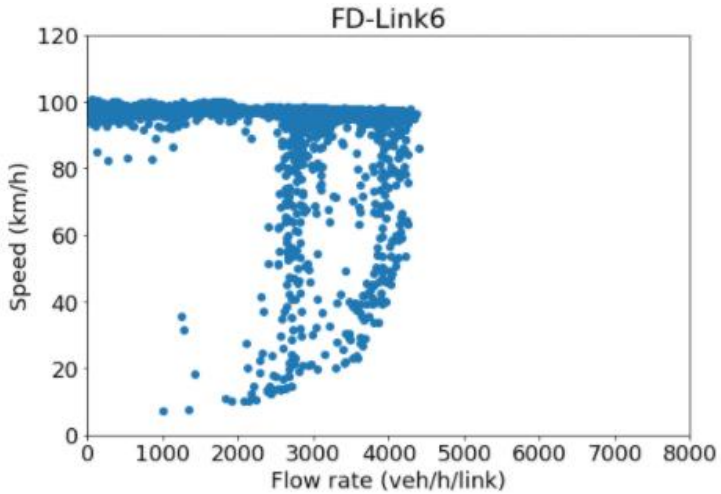
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Flow rate (veh/h/link)
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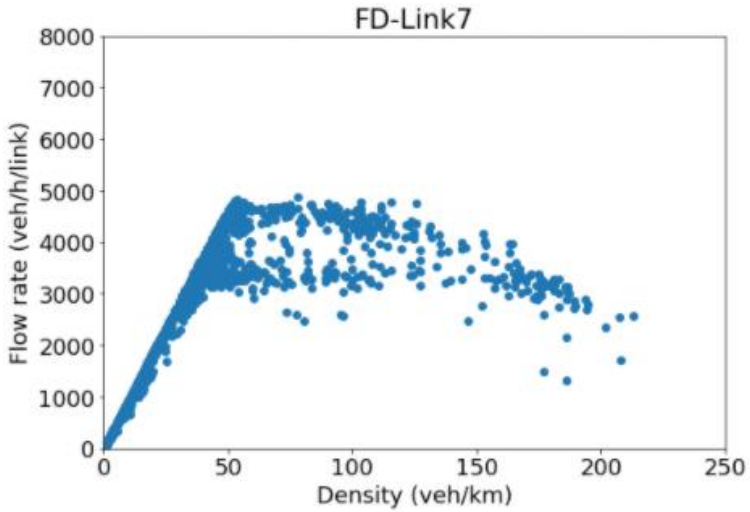
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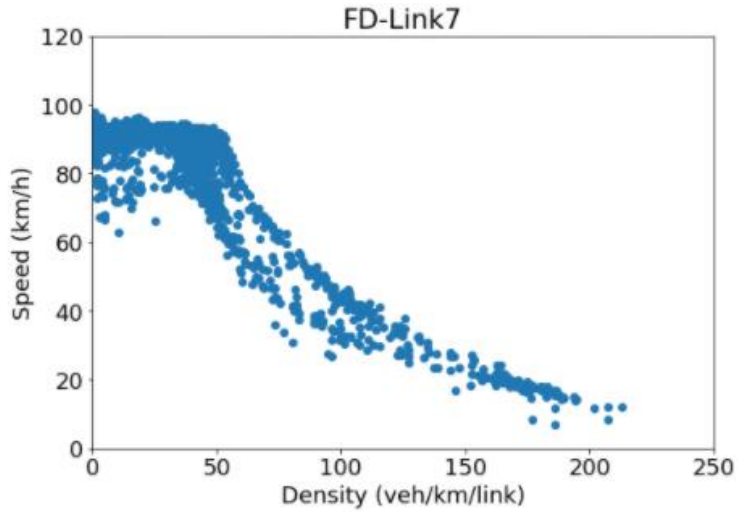
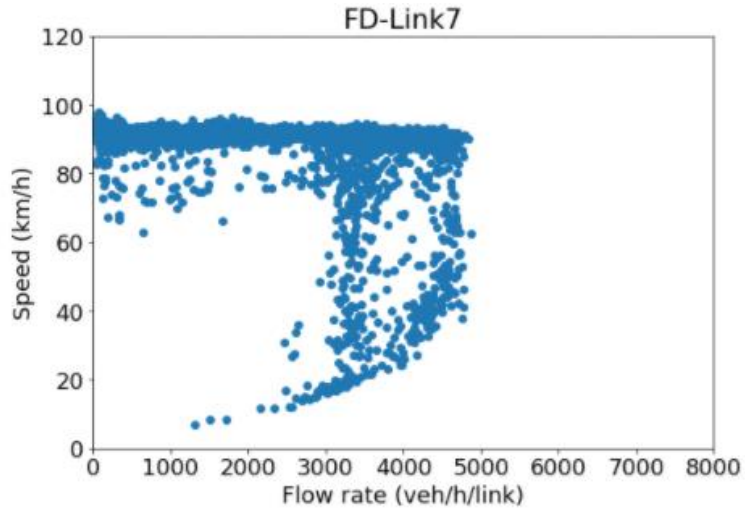
Flow rate (veh/h/link)
Density (veh/km)


FD-Link7
Speed (km/h)
Density (veh/km/link)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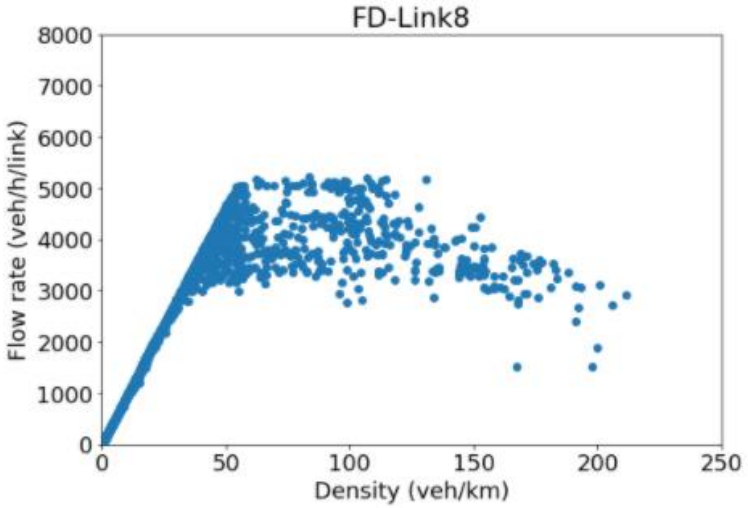
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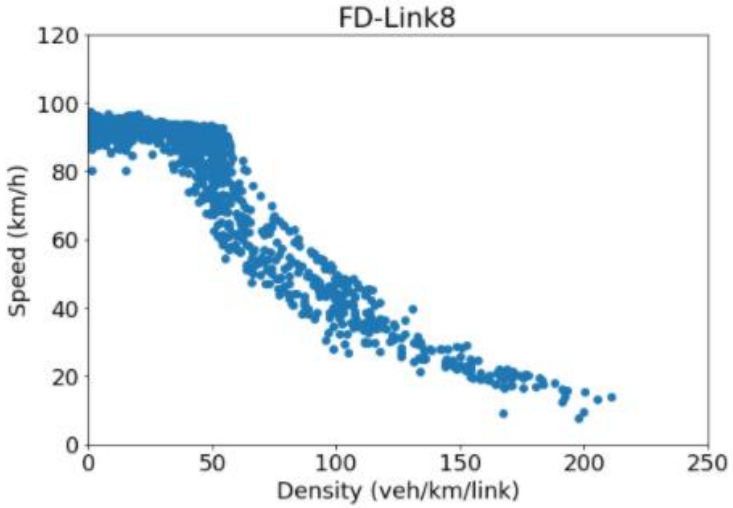
Density (veh/km)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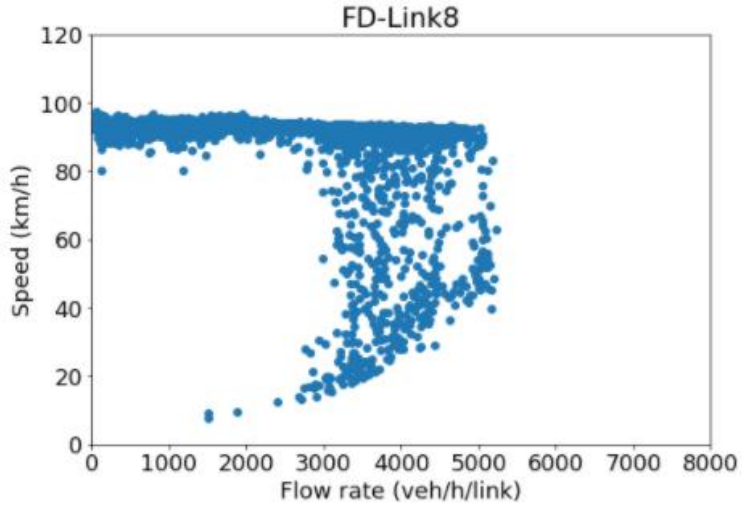
Speed (km/h)
Density (veh/km/link)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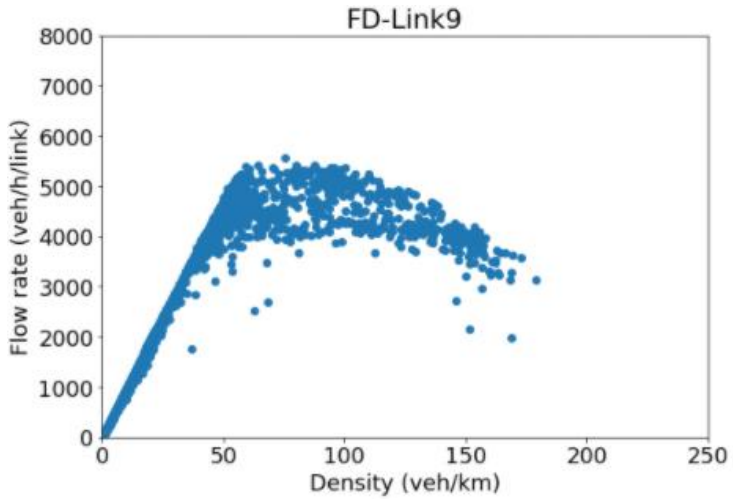
Flow rate (veh/h/link)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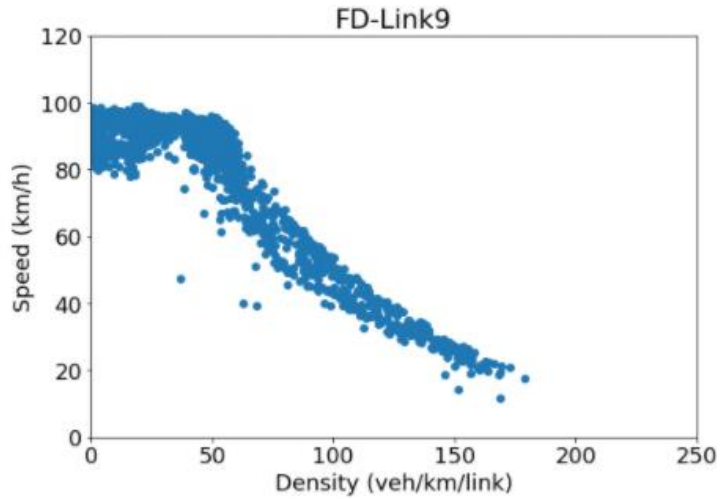
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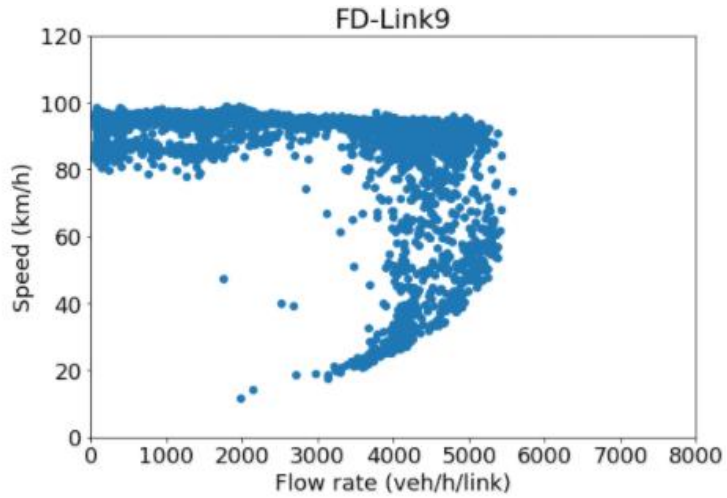
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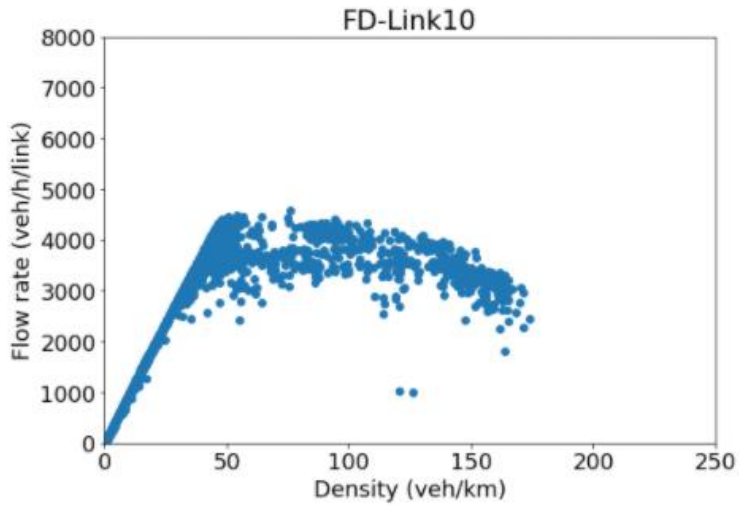
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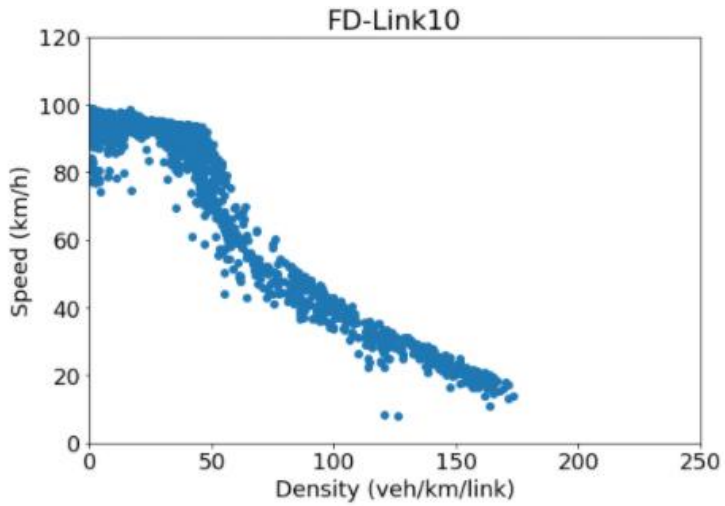
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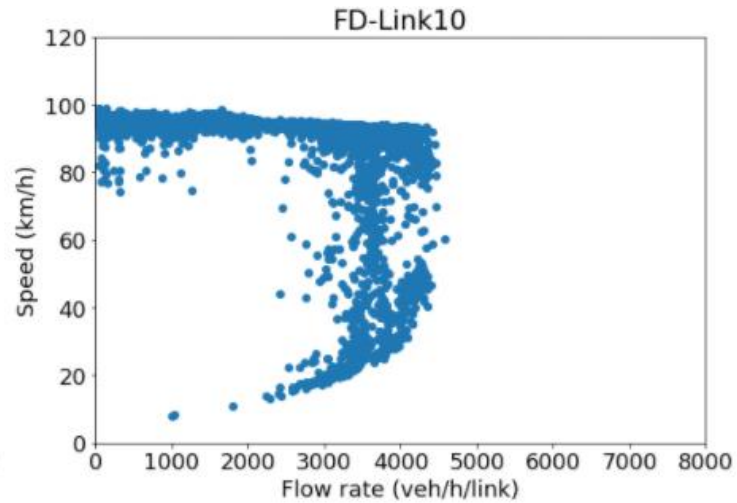
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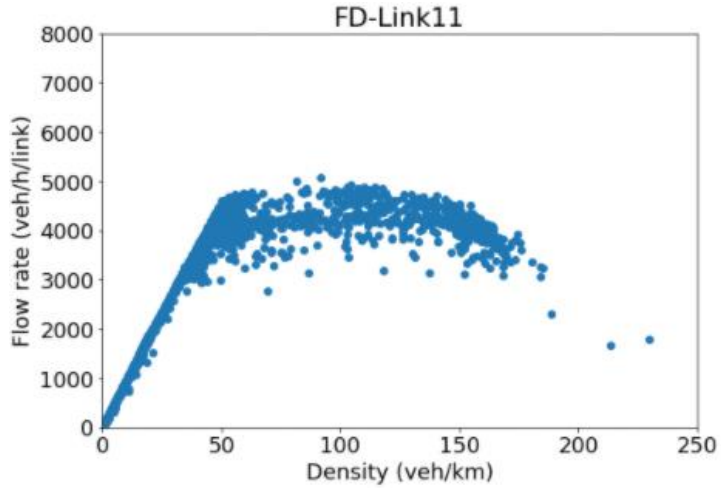
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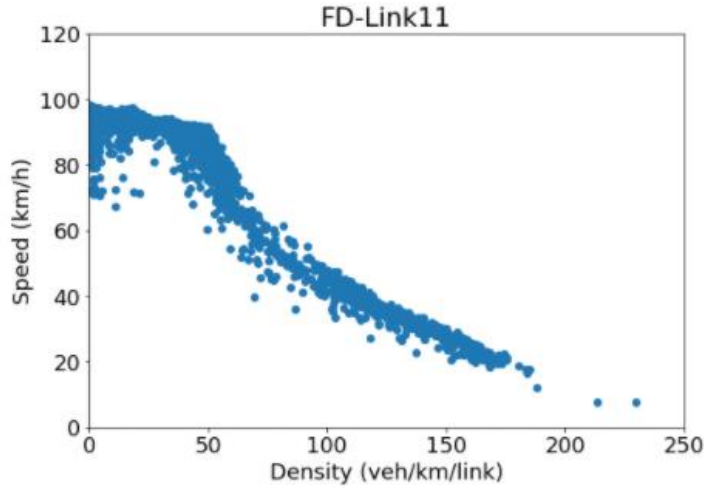
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Density (veh/km/link)
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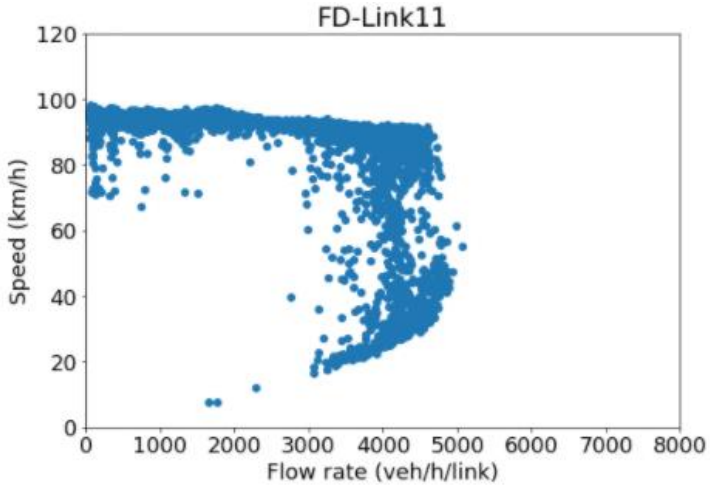
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Flow rate (veh/h/link)
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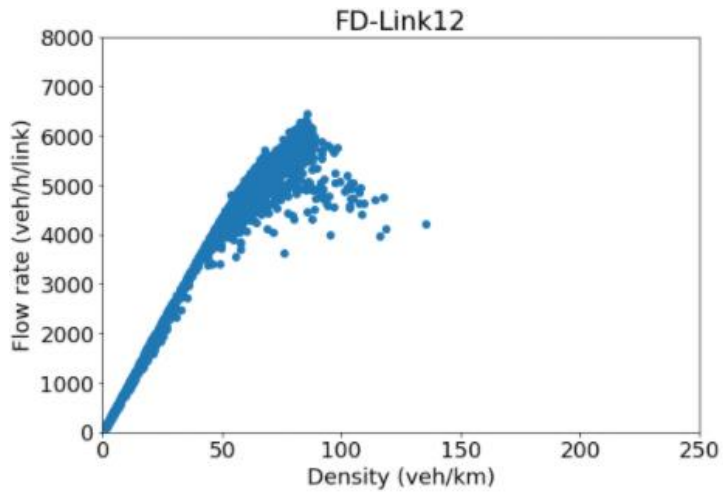
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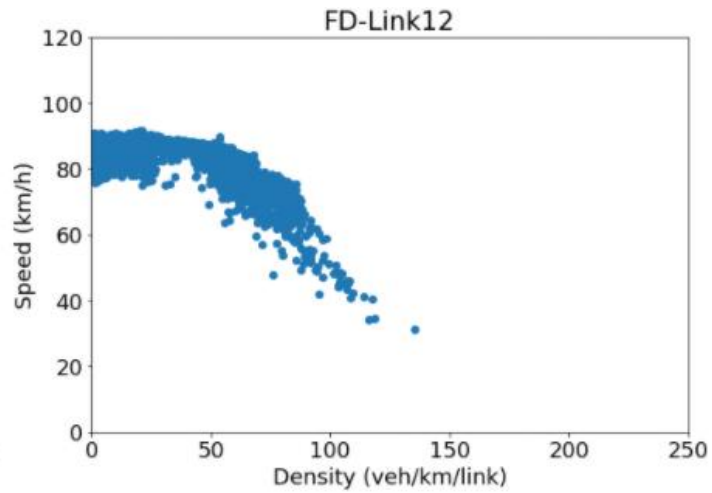
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Density (veh/km/link)
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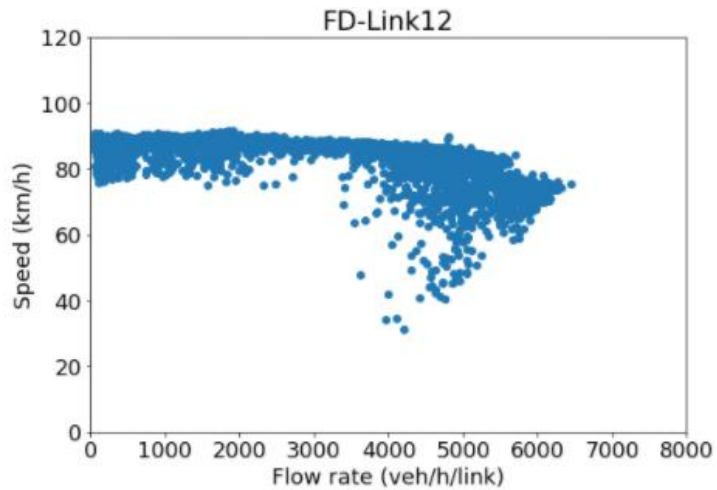
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Flow rate (veh/h/link)
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4000
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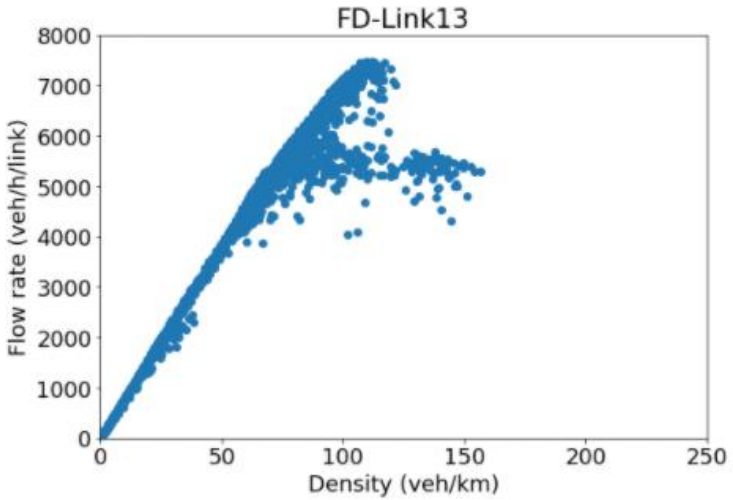
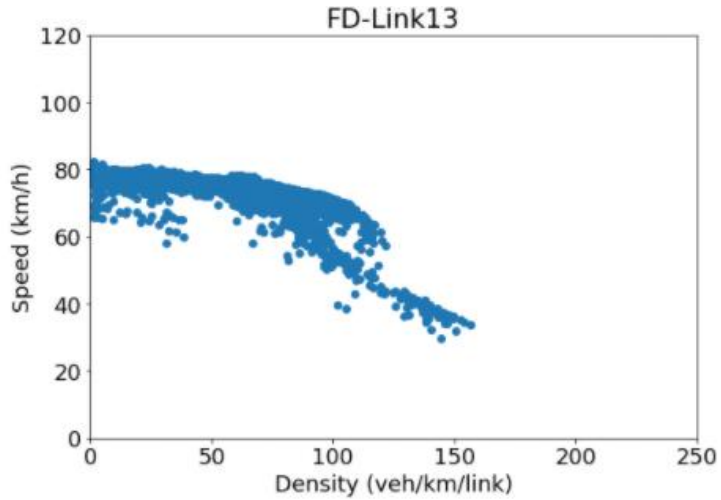
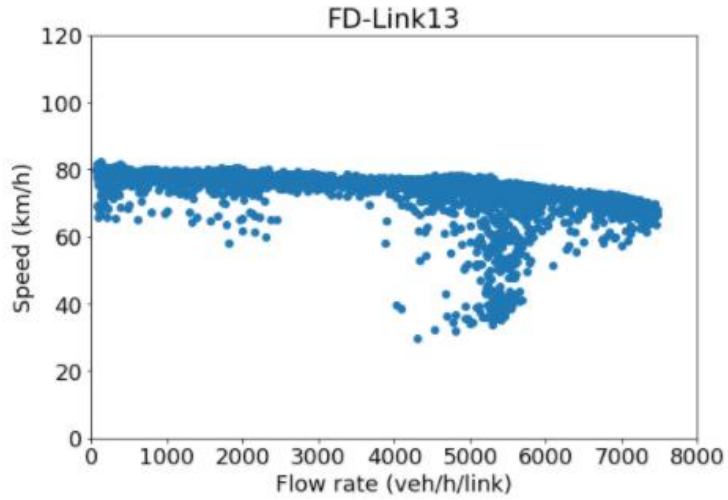
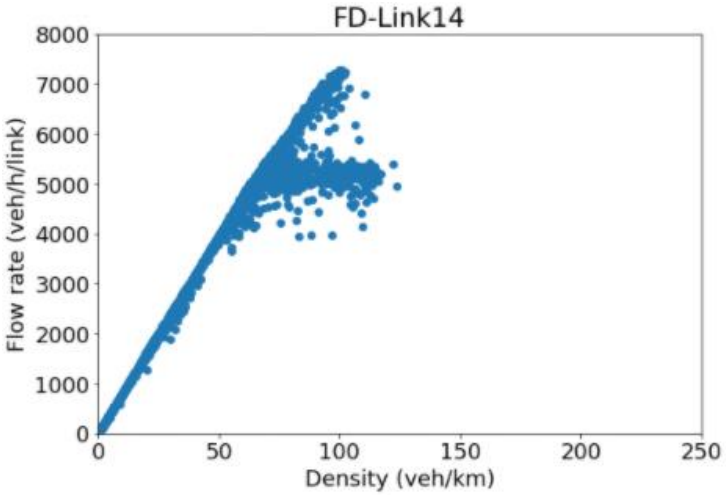
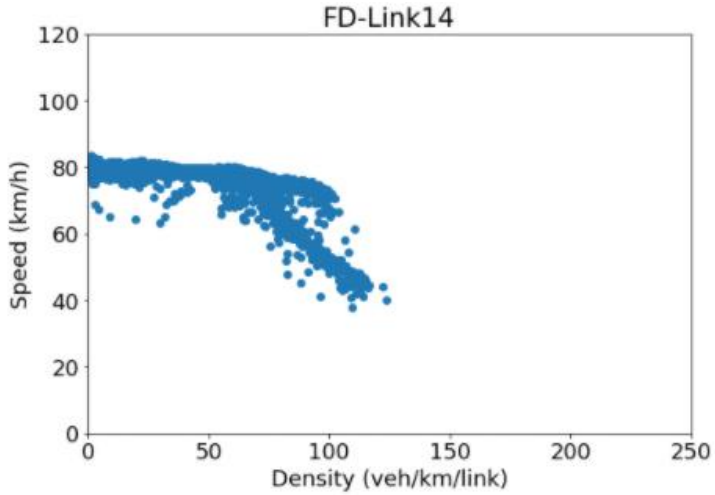
6000
7000
8000

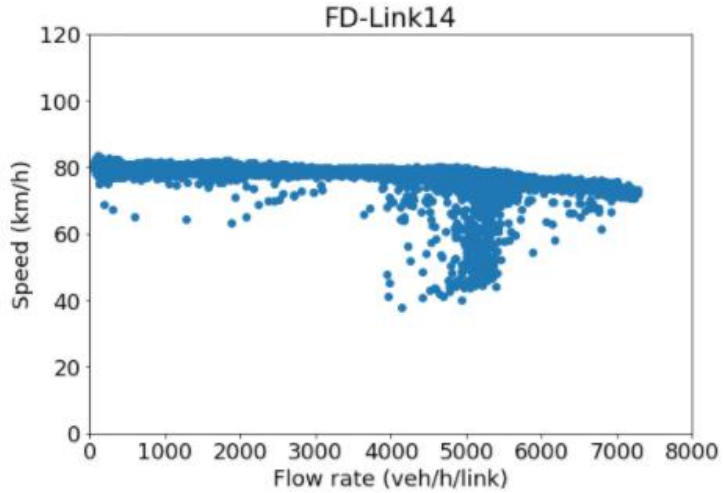

FD-Link13
Flow rate (veh/h/link)
Density (veh/km)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
50
100
150
200
250


FD-Link13
Speed (km/h)
Density (veh/km/link)
0
20
40
60
80
100
120
0
50
100
150
200
250

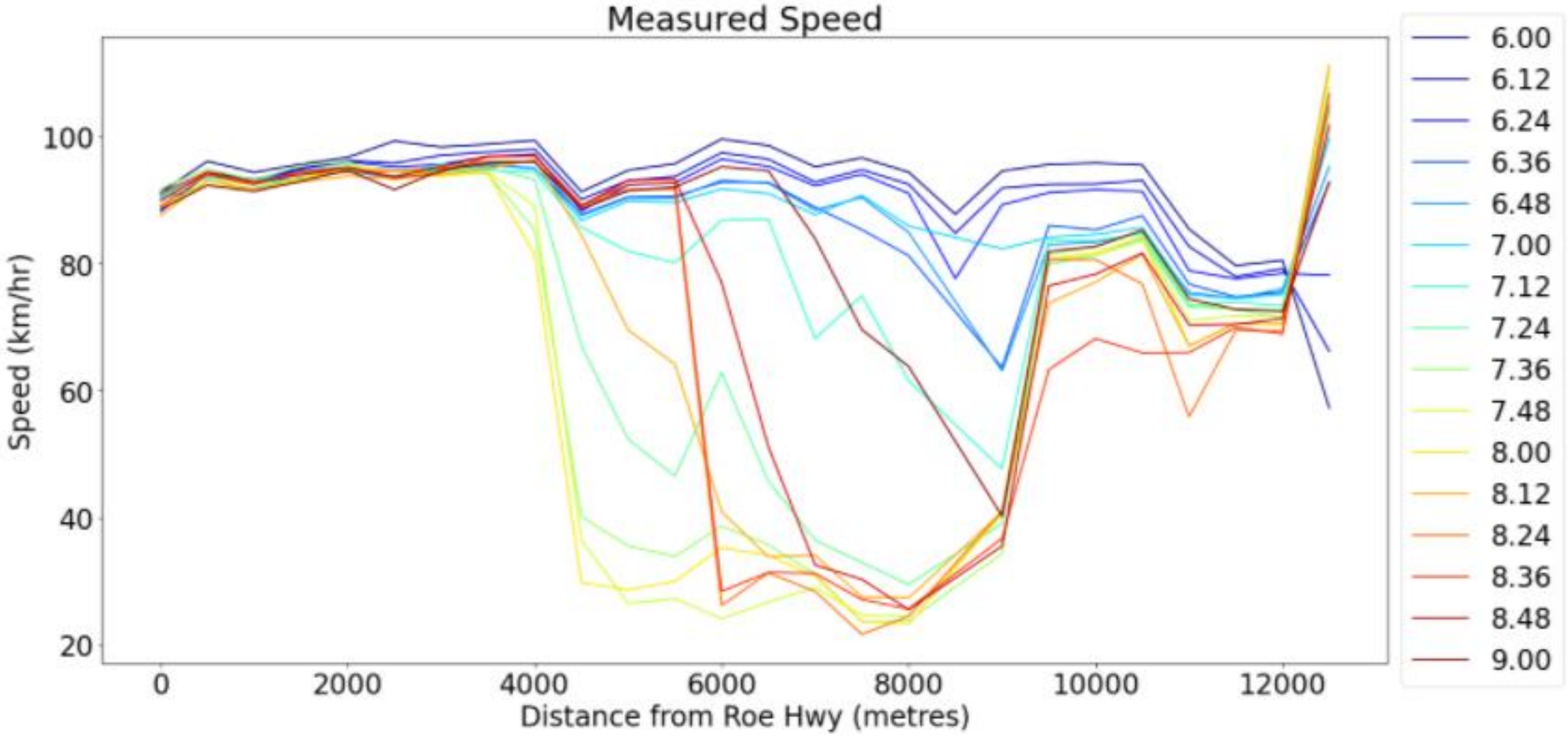

FD-Link13
Speed (km/h)
Flow rate (veh/h/link)
0
20
40
60
80
100
120
0
1000
2000
3000
4000
5000
6000
7000
8000


FD-Link14
Flow rate (veh/h/link)
Density (veh/km)
0
1000
2000
3000
4000
5000
6000
7000
8000
0
50
100
150
200
250

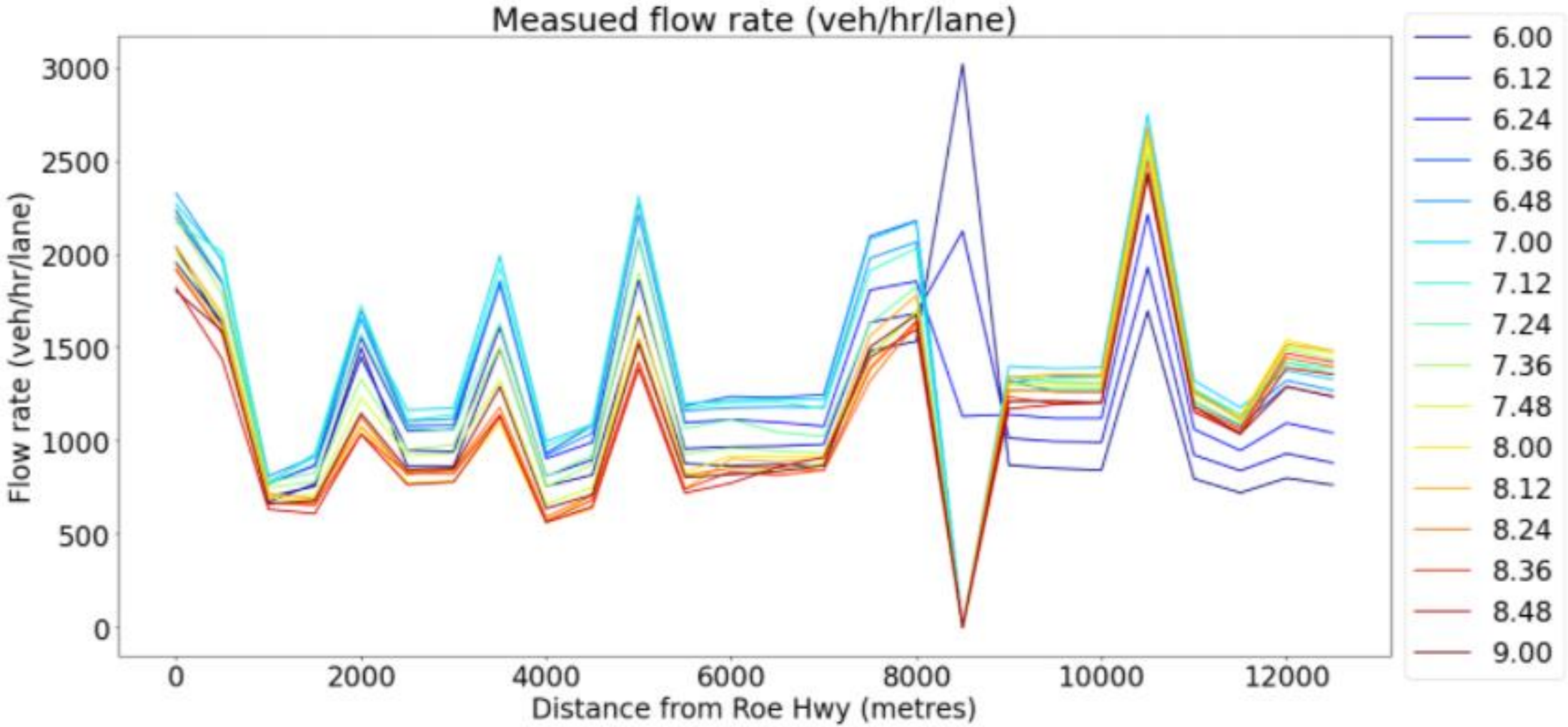

FD-Link14
Speed (km/h)
Density (veh/km/link)
0
20
40
60
80
100
120
0
50
100
150
200
250


FD-Link14
Speed (km/h)
Flow rate (veh/h/link)
0
20
40
60
80
100
120
0
1000
2000
3000
4000
5000
6000
7000
8000

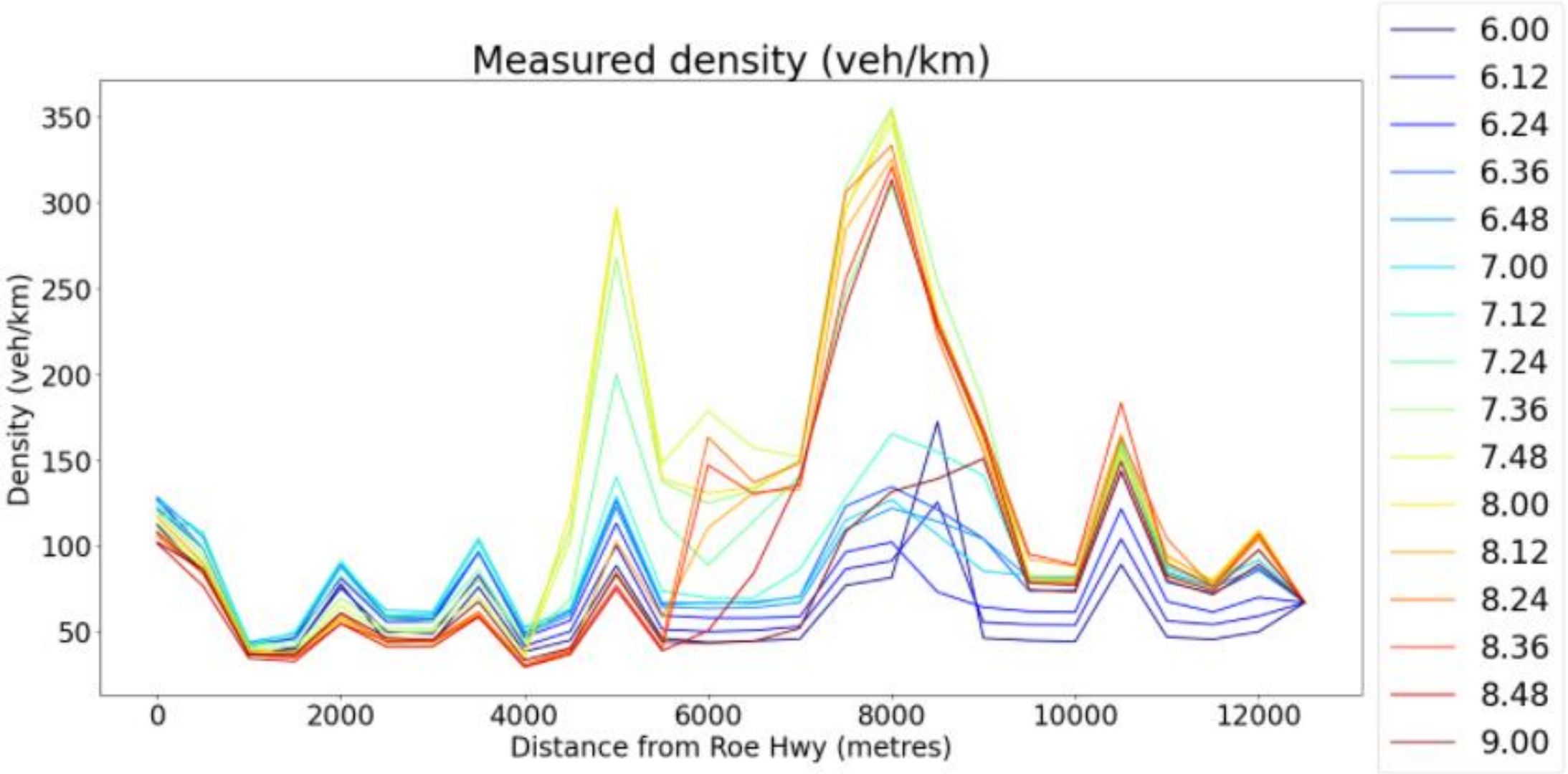
Measured Data - Speed



Measured Data – Flow rate

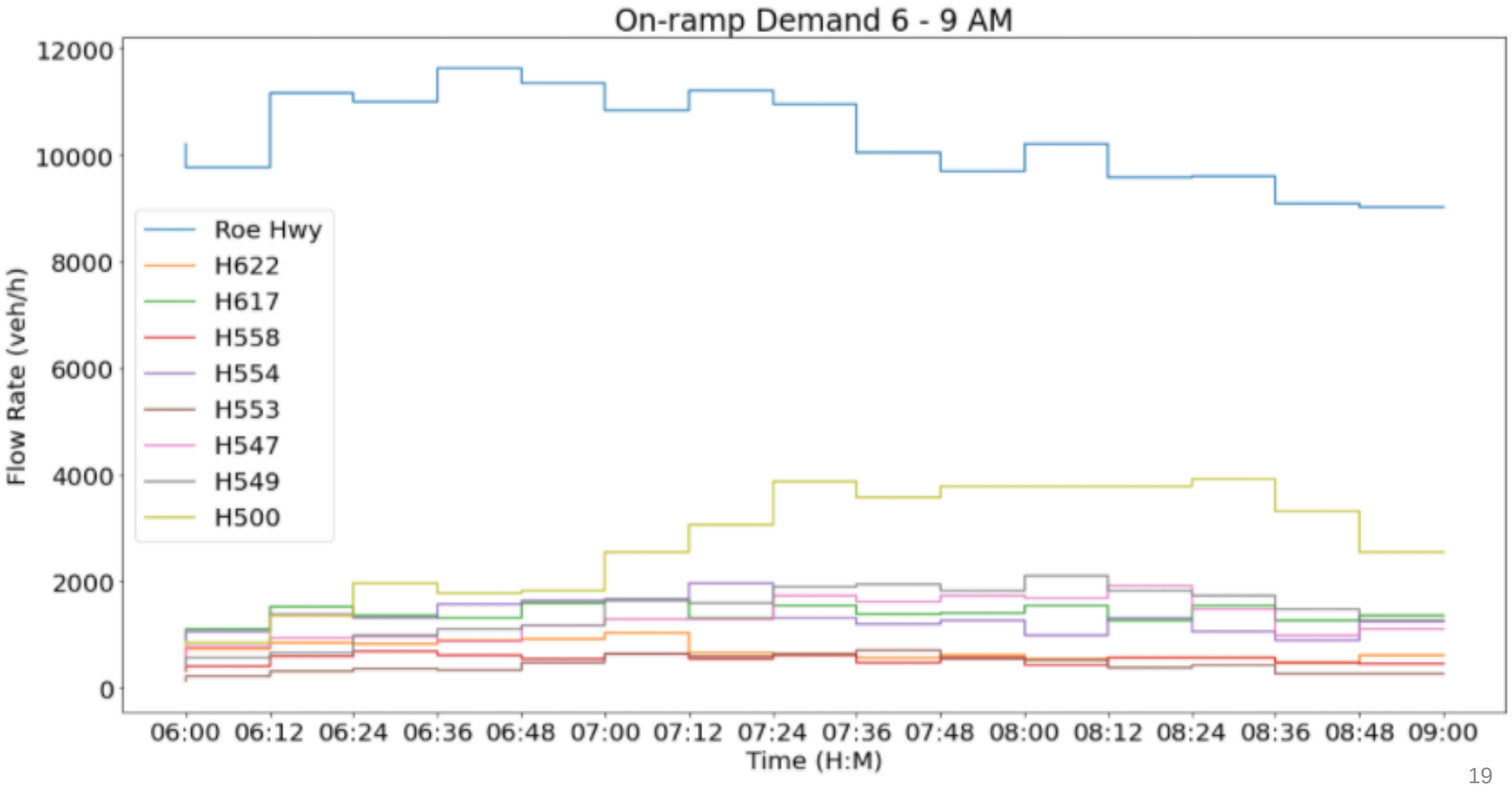


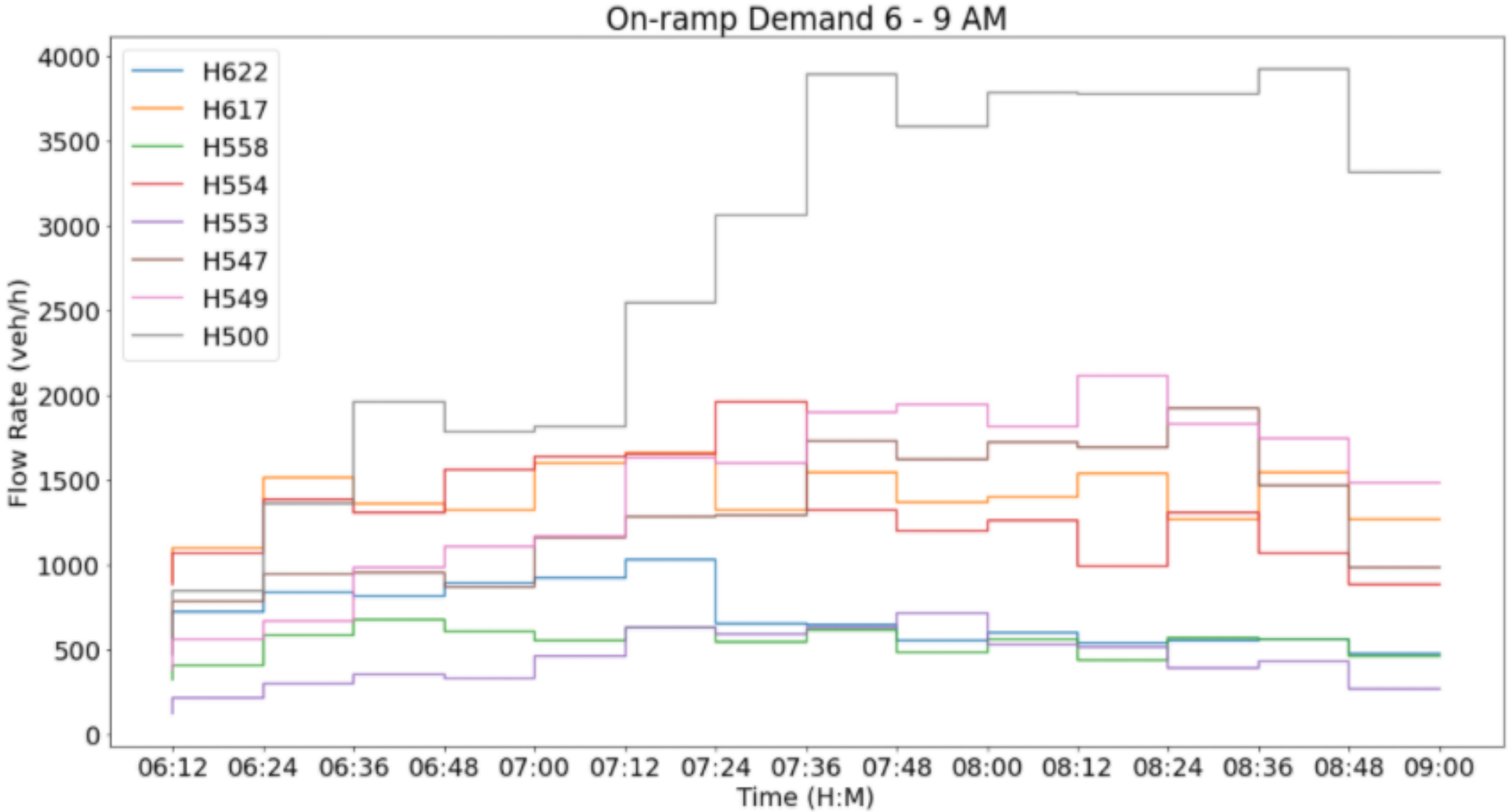
Measured Data – Density

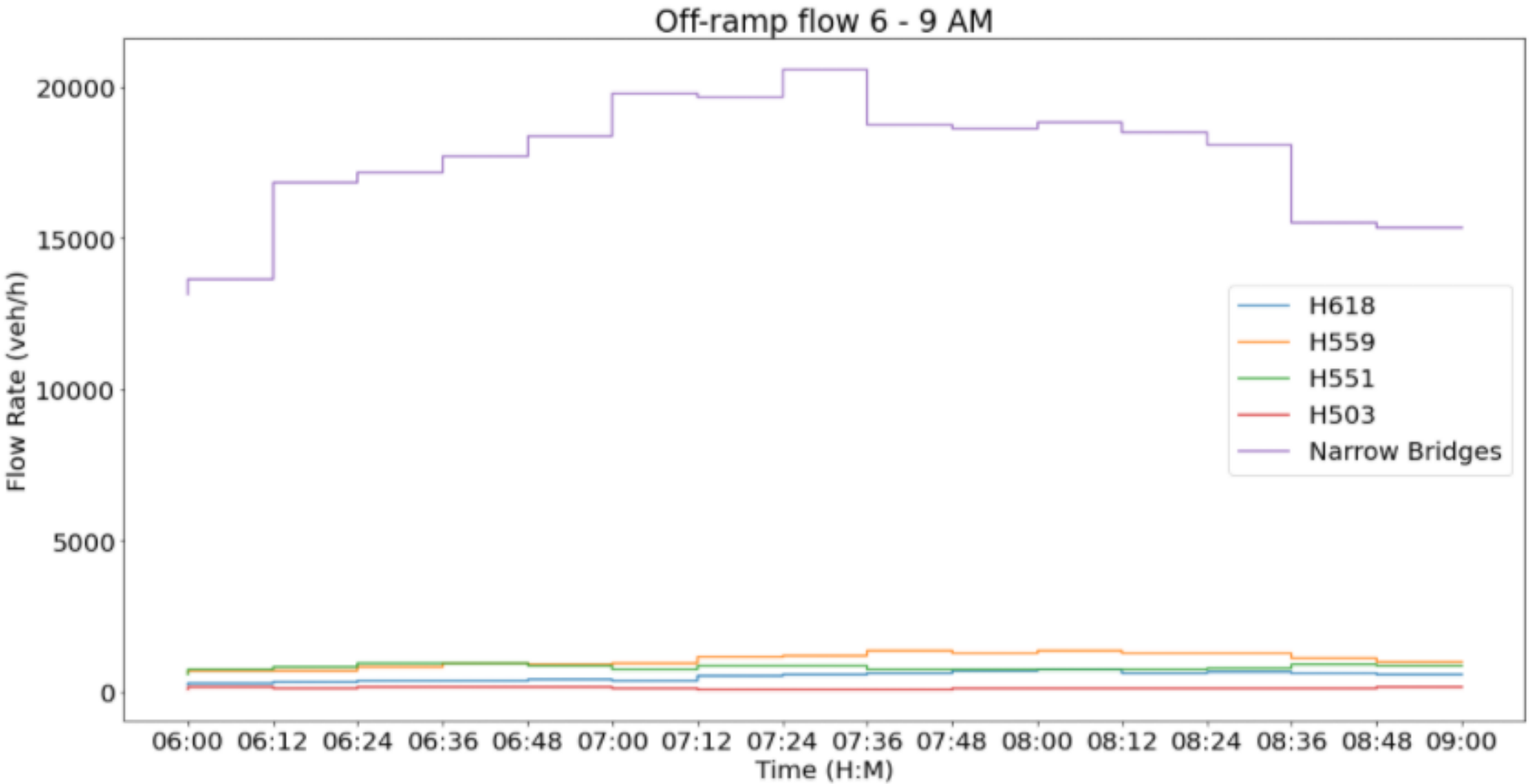


CNN – LSTM Predicted Data (every 12 minutes)

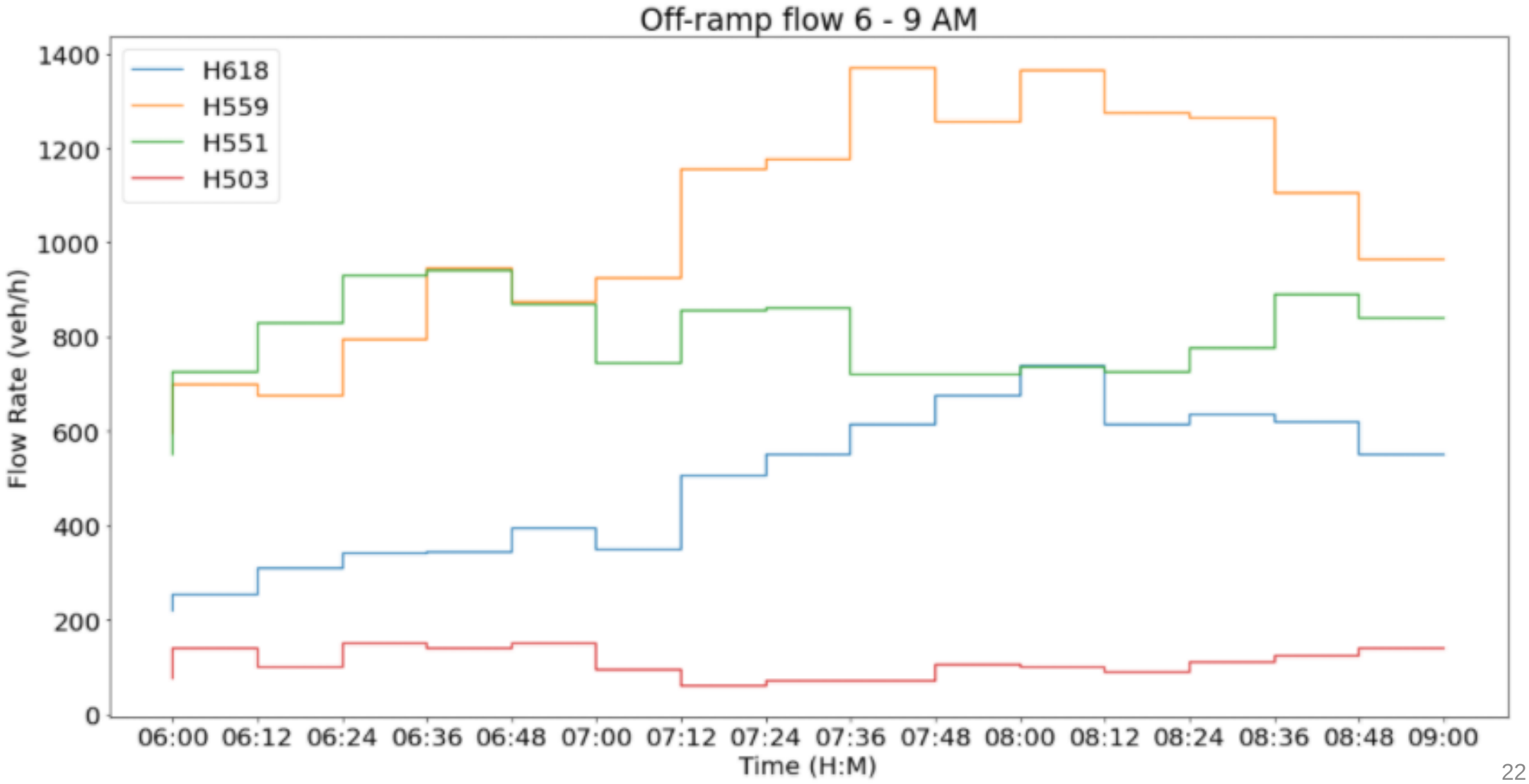
Estimated Incoming flow




On-ramp Demand 6 - 9 AM
H622
H617
H558
H554
H553
H547
H549
H500
Flow Rate (veh/h)
0
500
1000
1500
2000
2500
3000
3500
4000
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00
Time (H:M)


Off-ramp flow 6 - 9 AM
Flow Rate (veh/h)
20000
15000
10000
5000
0
06:00
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00
Time (H:M)
H618
H559
H551
H503
Narrow Bridges

Estimated Off-ramp outgoing flow



LP Control of congestion through RM

Aim: To obtain optimal on-ramp flows while minimizing flow disruptions on the mainline and preventing spillback from affecting the surrounding arterial roads.

$$\max \sum_{j=1}^{N_R} \alpha_j r_{j,t}$$

subject to,

- $\sum_{i=2}^{N_R+1} \beta_{i,j}\, r_{j,t} \leq \min\{0;\ \boldsymbol{\gamma_i C_i} - \Delta \boldsymbol{Q_{i,t-1}} - \boldsymbol{\beta_{1,j} Q_{1,t}}\}$
- $0 \leq r_{j,t} \leq d_{j,t} + \frac{1}{T} m_{j,t}$,

$$m_{j,t} = m_{j,t-1} + T\left(d_{j,t-1} - r_{j,t-1}\right)$$

$0 \leq m_{j,t} \leq m_{max}$ and $\alpha_j = \frac{1}{N_S} \sum_{k=0}^{N_S-1} L_{j,k}$

$r_{j,t}$: decision variables representing inflow to freeway from on-ramp j at time t

α_j : mean trip length (km)

$\beta_{i,j}(t)$: ratio of traffic volume on each section i with the inflow from each ramp j

C_i : flow capacity of section i

$\boldsymbol{\gamma_i} \in (\mathbf{0}, \mathbf{1}]$ **service level of section** $\boldsymbol{i}$

m_j : queue length of ramp j

$d_j(t)$: estimated on-ramp demand

$q_0(t)$: estimated traffic volume from Roe Hwy

Ratio of traffic on each section i with the inflow from each source j

$$\beta_{i,j}(t) = \sum_{k=0}^{N_S} w_{i,k} \frac{X_{j,k}(t)}{d_j(t)},$$

where $X_{j,k}(t)$ are calculated by the linear constrained optimization problem

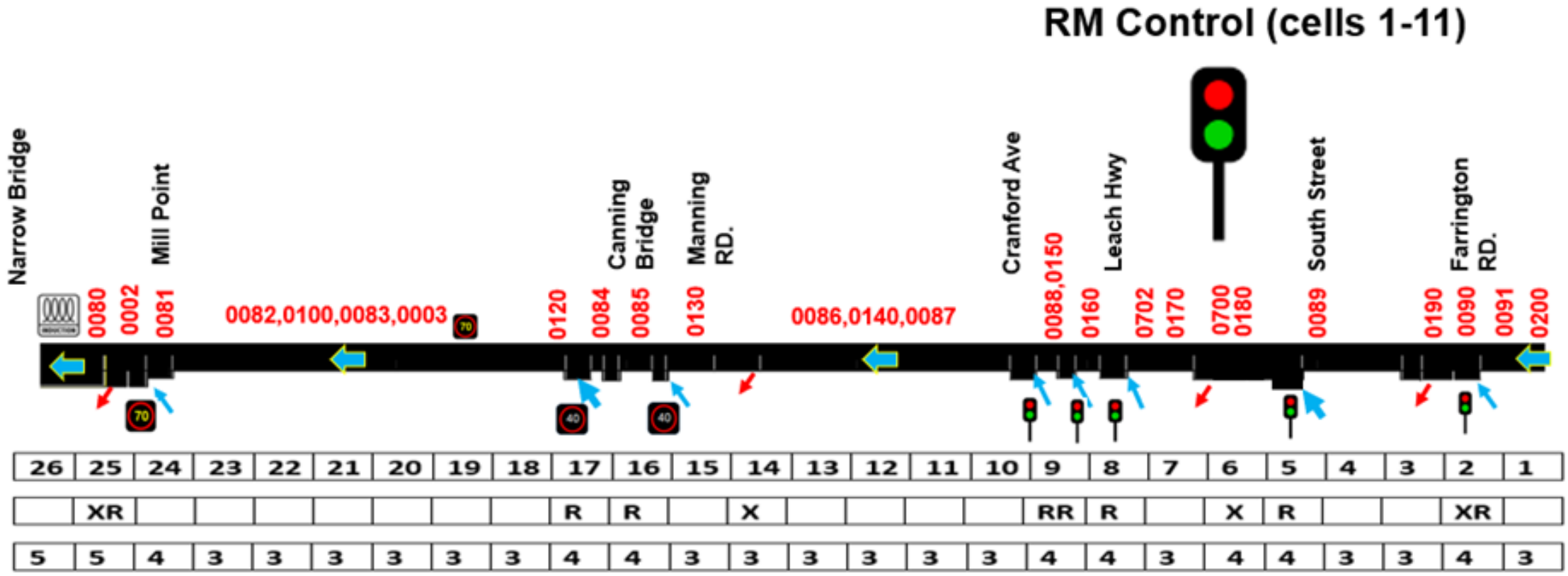
$$\min \sum_{k=1}^{N_S+1} \sum_{j=1}^{N_R+1} C_{j,k} X_{j,k}(t) \quad X_{jk}(t) \geq 0$$

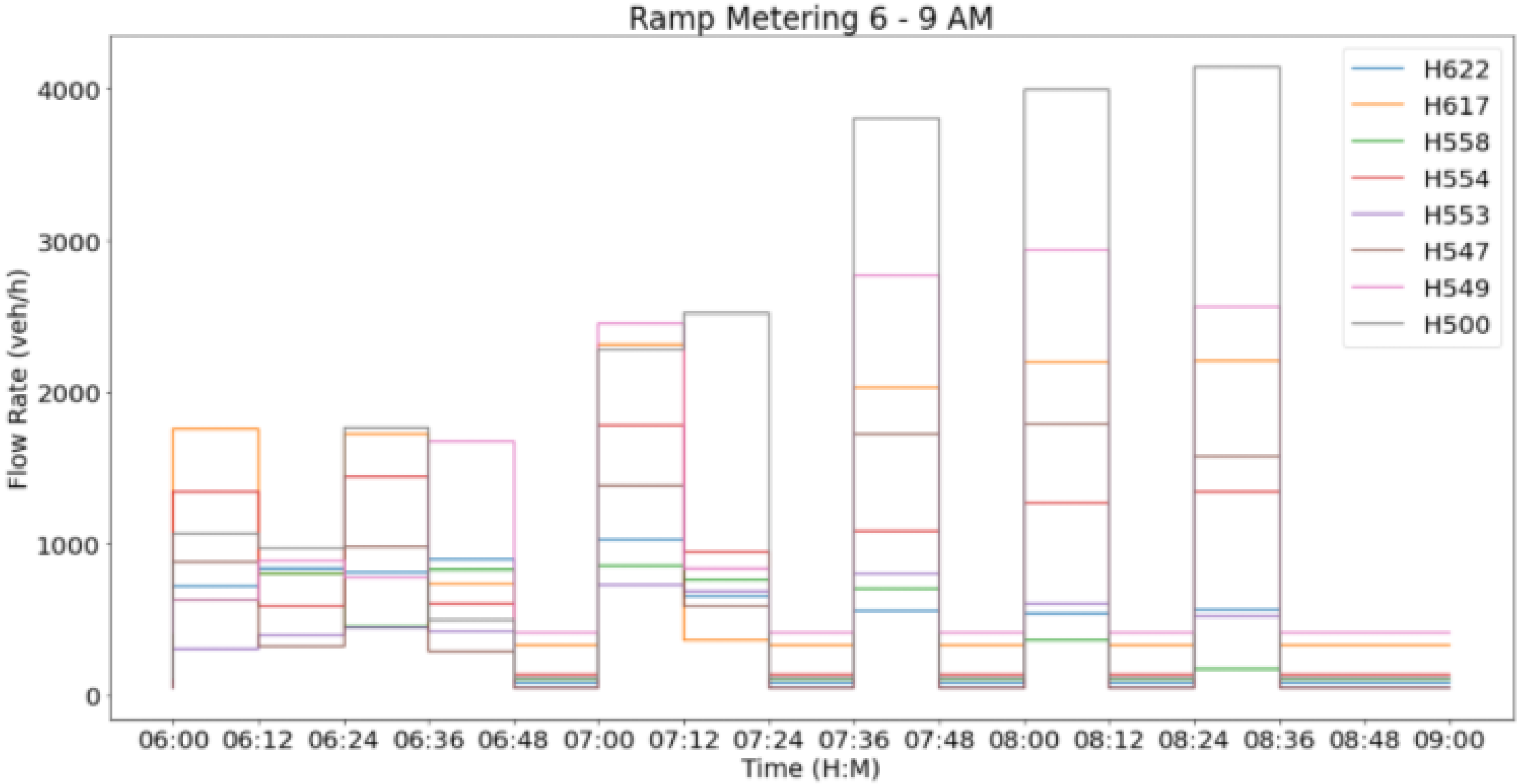
subject to

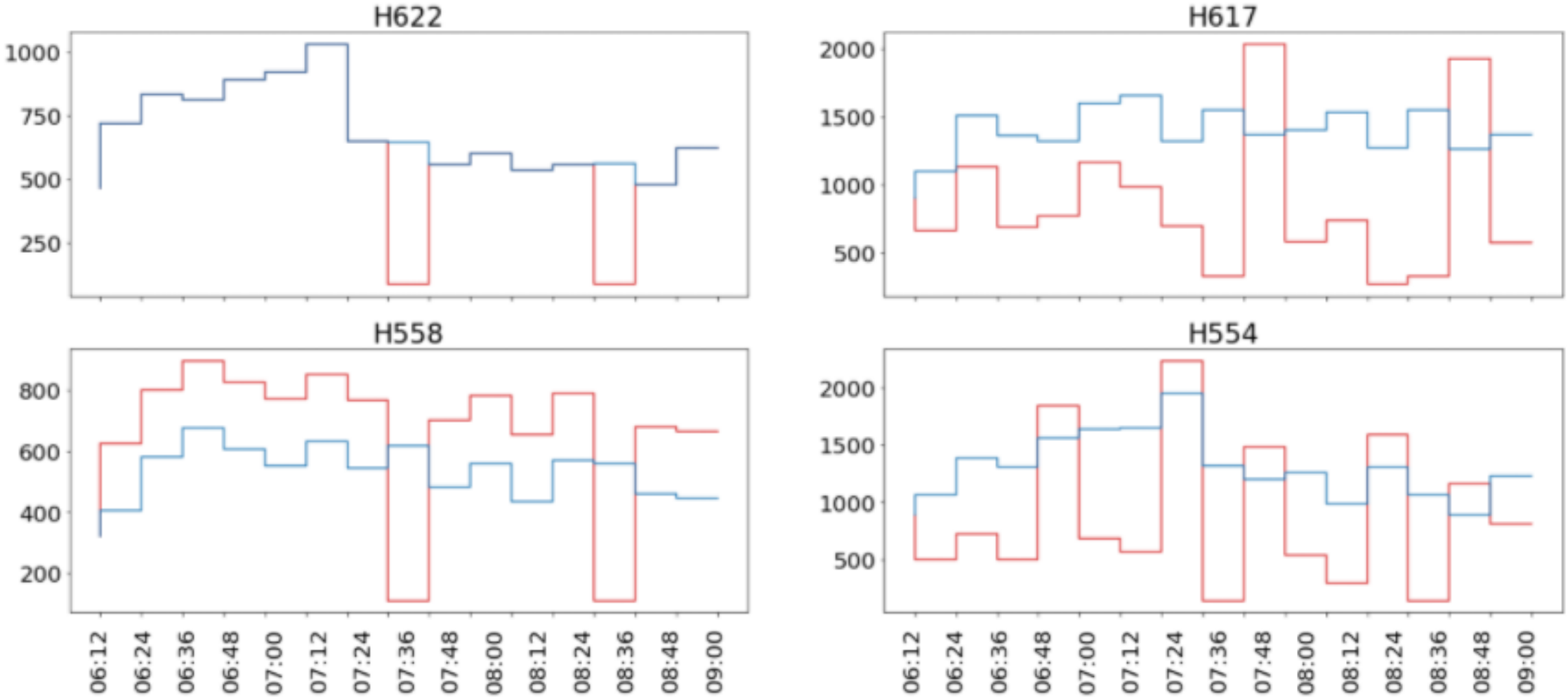
$$\sum_{k=1}^{N_S+1} X_{j,k}(t) = d_j(t), \qquad j = 1, \ldots, N_R + 1$$

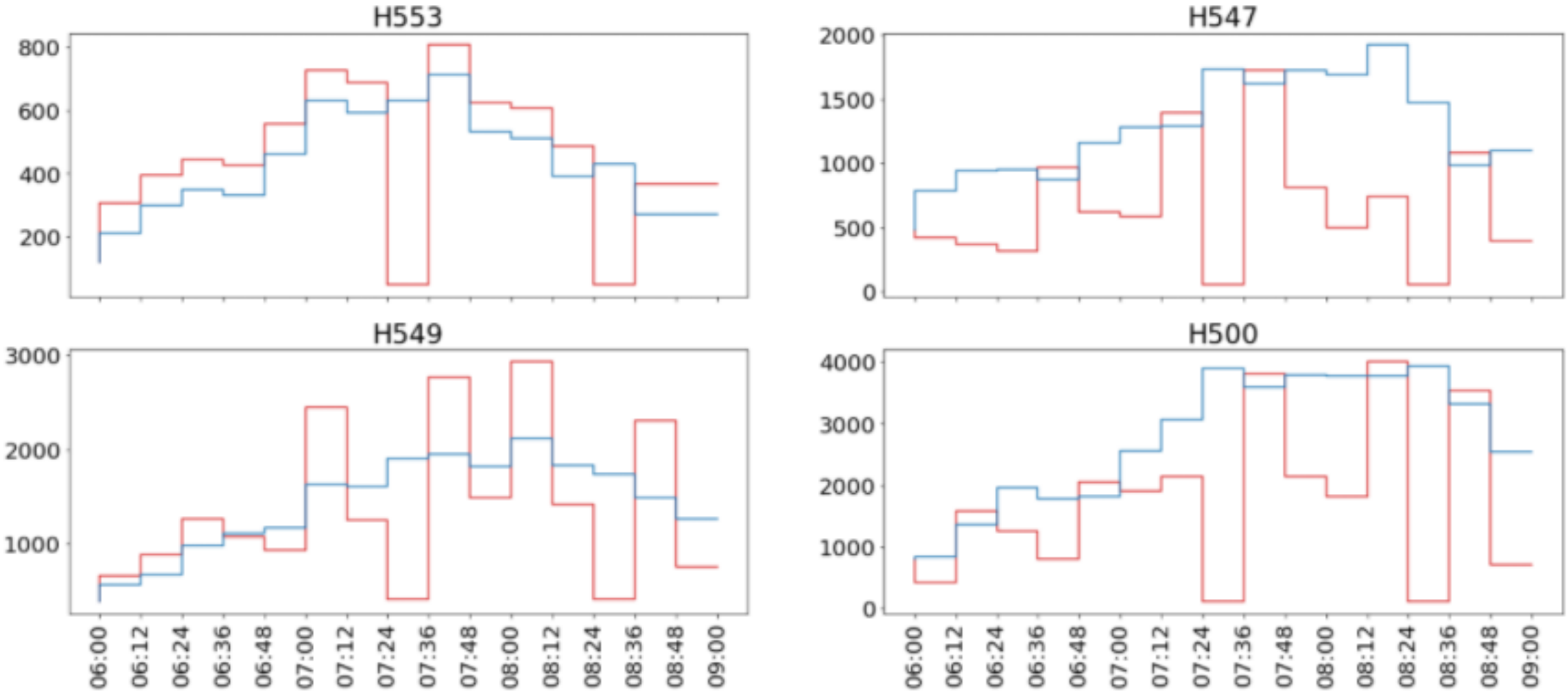
$$\sum_{j=1}^{N_R+1} X_{j,k}(t) = s_k(t), \qquad k = 0, \ldots, N_S + 1$$

Service level $\gamma = 1.0$




Ramp Metering 6 - 9 AM
Flow Rate (veh/h)
0
1000
2000
3000
4000
06:00
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00
Time (H:M)
H622
H617
H558
H554
H553
H547
H549
H500


H622
1000
750
500
250
H617
2000
1500
1000
500
H558
800
600
400
200
H554
2000
1500
1000
500
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00

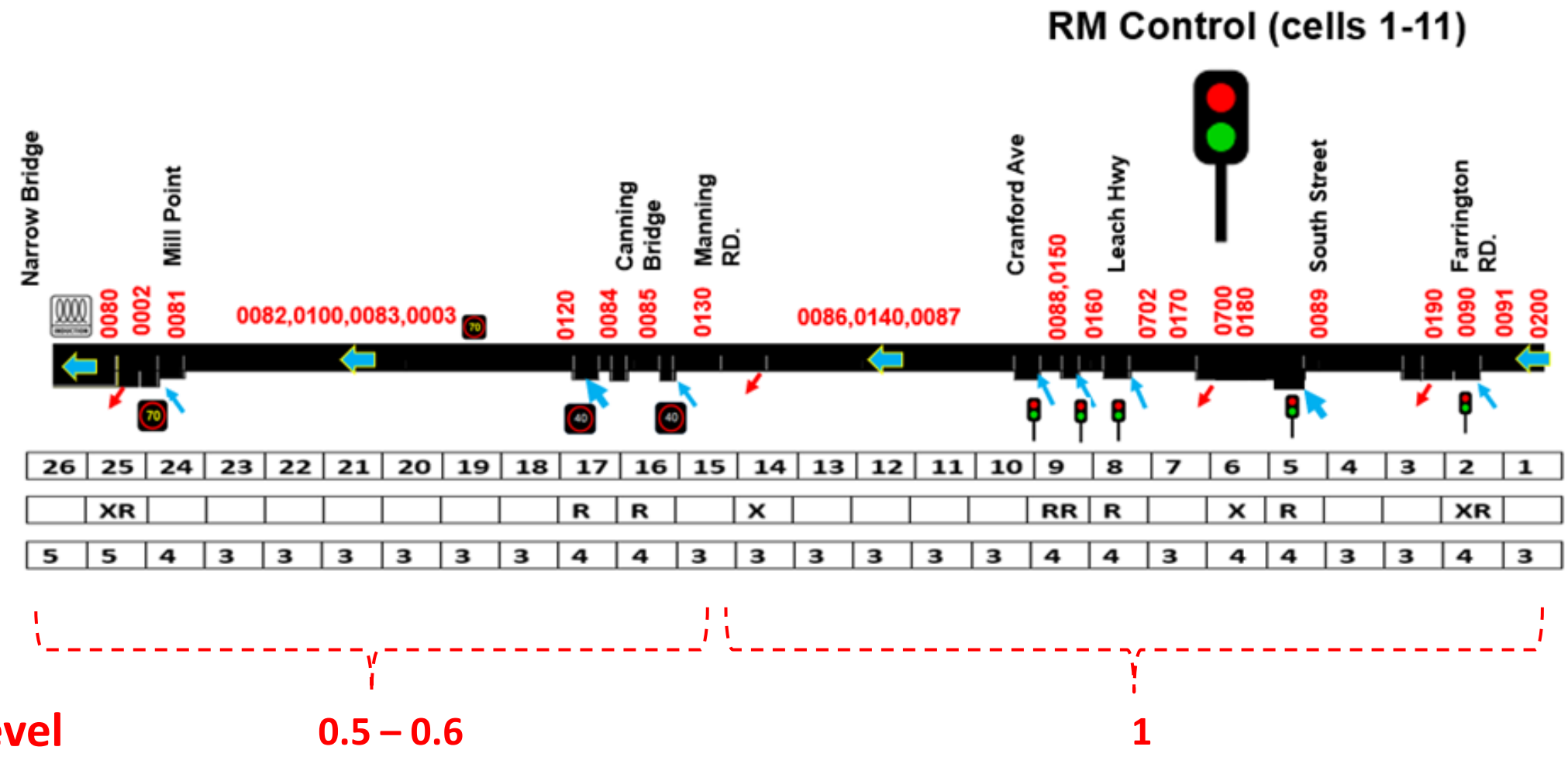

H553
800
600
400
200
H547
2000
1500
1000
500
0
H549
3000
2000
1000
H500
4000
3000
2000
1000
0
06:00
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00

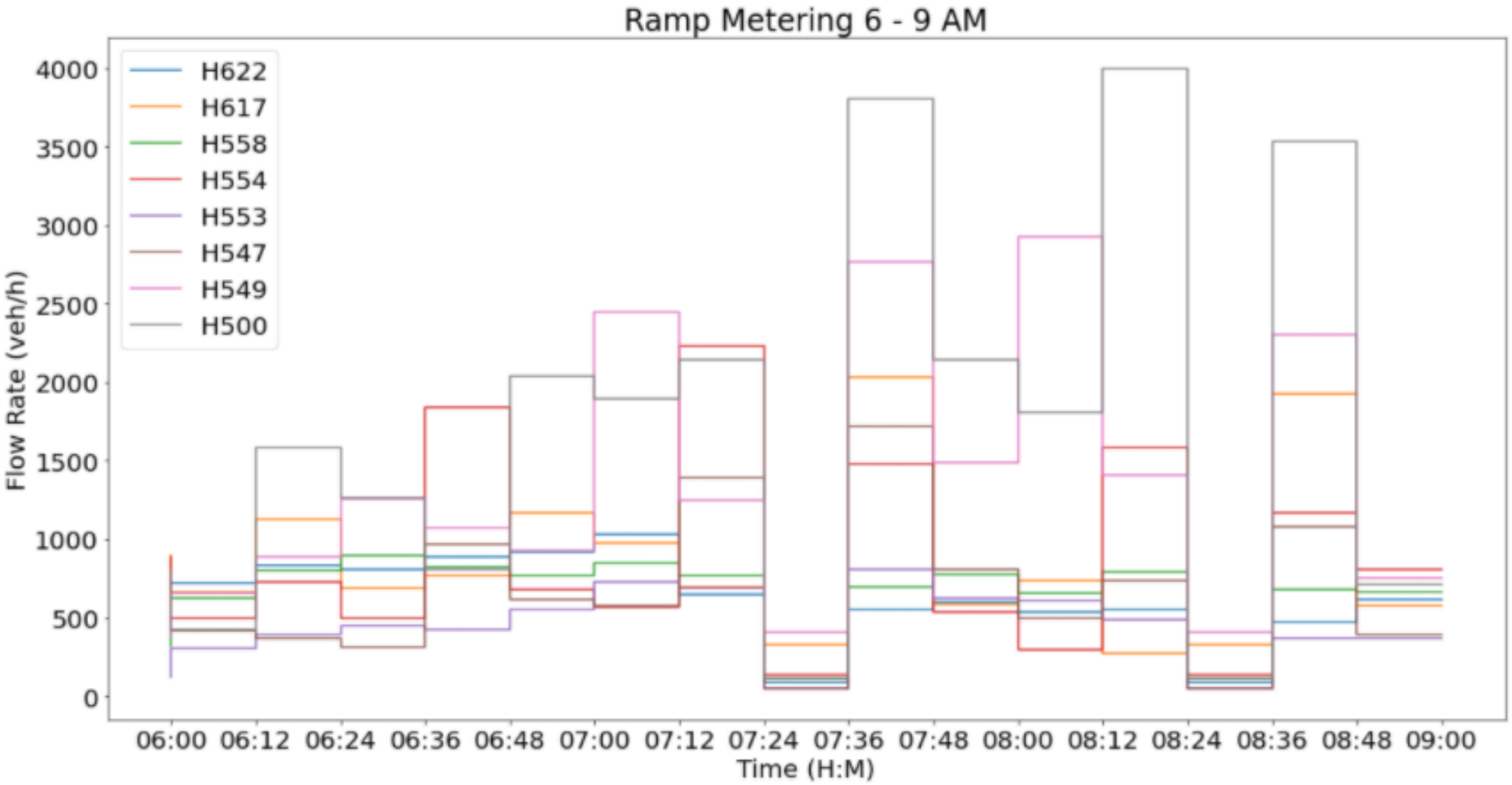
Emergency control phase

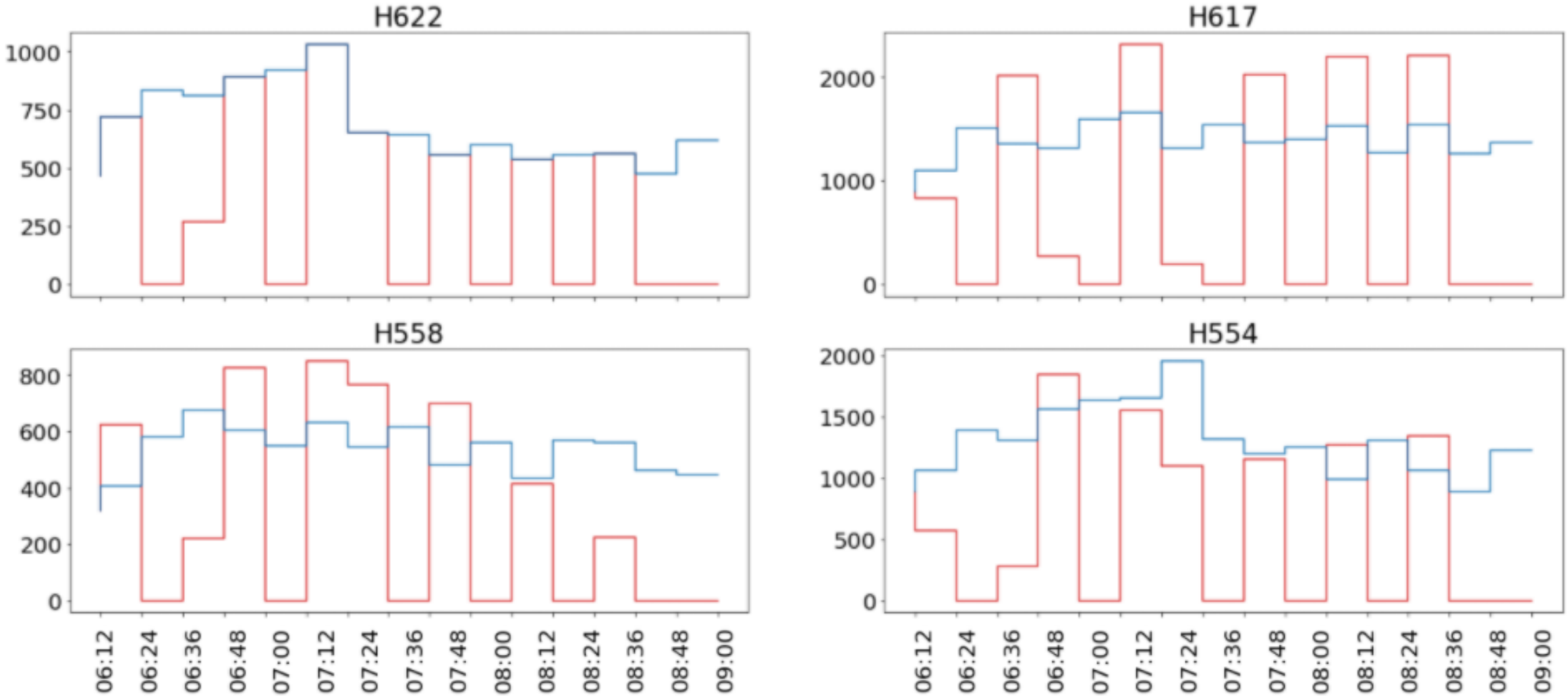
Aim: To dissolve congestion quickly to avoid capacity reductions and flow breakdown due to incidents.

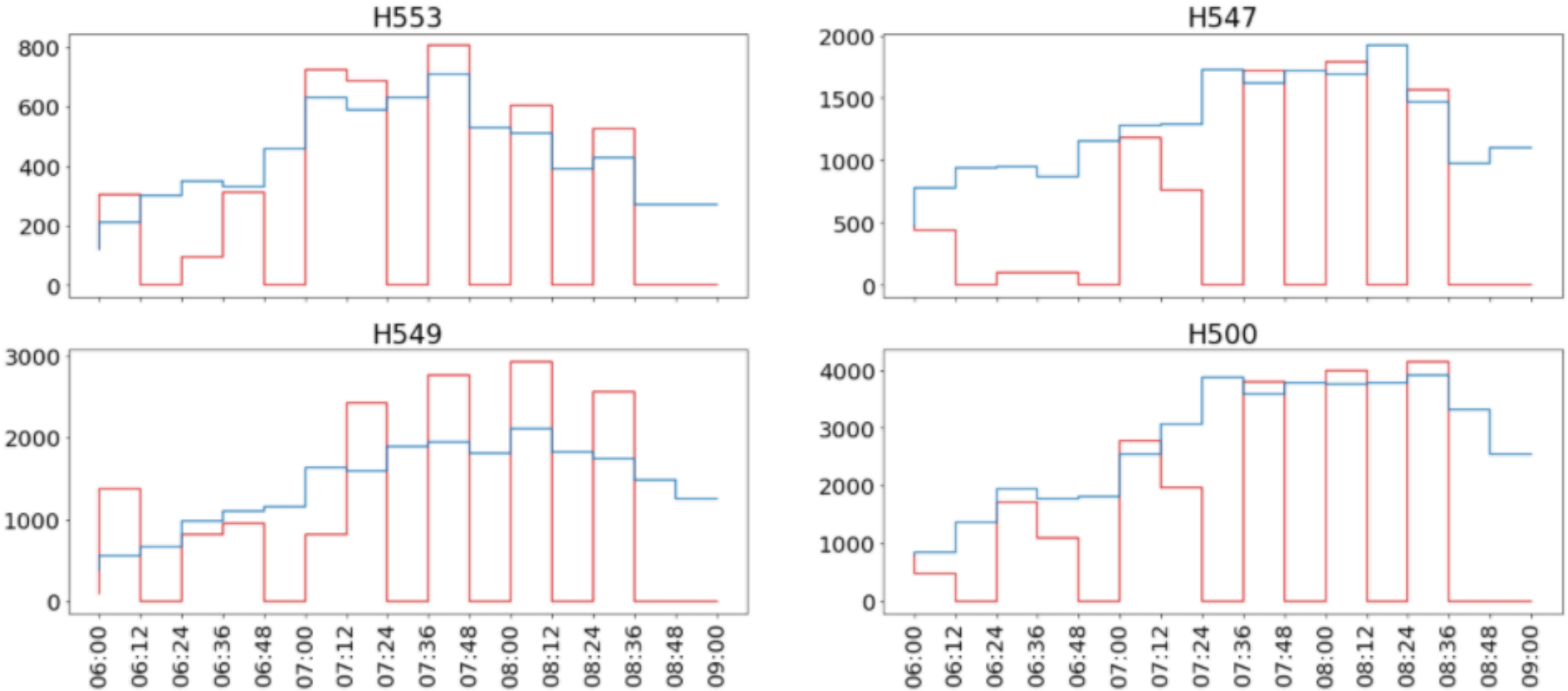
Using Variable Message Signs (VMS).

- **Upstream on-ramps are closed** successively in accordance with the severity of the congestion.
- Off-line analyses and simulations are used to determine when and where sequential control should be used, including which ramps should be restricted or closed.


RM Control (cells 1-11)
Narrow Bridge
Mill Point
Canning Bridge
Manning RD.
Cranford Ave
Leach Hwy
South Street
Farrington RD.
0080
0002
0081
0082,0100,0083,0003
0120
0084
0085
0130
0086,0140,0087
0088,0150
0160
0702
0170
0700
0180
0089
0190
0090
0091
0200
26 25 24 23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
XR R R X RR R X R XR
5 5 4 3 3 3 3 3 3 4 4 3 3 3 3 3 3 4 4 3 4 4 3 3 4 3
Service level
0.5 – 0.6
1


Ramp Metering 6 - 9 AM
H622
H617
H558
H554
H553
H547
H549
H500
Flow Rate (veh/h)
4000
3500
3000
2500
2000
1500
1000
500
0
06:00
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00
Time (H:M)


H622
1000
750
500
250
0
H617
2000
1000
0
H558
800
600
400
200
0
H554
2000
1500
1000
500
0
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00


H553
800
600
400
200
0
H547
2000
1500
1000
500
0
H549
3000
2000
1000
0
H500
4000
3000
2000
1000
0
06:00
06:12
06:24
06:36
06:48
07:00
07:12
07:24
07:36
07:48
08:00
08:12
08:24
08:36
08:48
09:00

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THANK YOU

For Your Attention