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TRANSPORTATION RESEARCH BOARD

Analyzing Corridors and Systems with the Highway Capacity Manual

March 25, 2021

2:00-3:30 PM Eastern

@NASEMTRB
#TRBwebinar

PDH Certification Information:

- 1.5 Professional Development Hours (PDH) – see follow-up email for instructions
- You must attend the entire webinar to be eligible to receive PDH credits
- Questions? Contact Reggie Gillum at RGillum@nas.edu

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REGISTERED CONTINUING EDUCATION PROGRAM

Learning Objectives

1. Quantify the impacts of spillback and travel time.

2. Utilize the HCM tools for evaluating congestion at the system level.

Lily Elefteriadou
elefter@ce.ufl.edu
University of Florida

Fabio Sasahara
fsasahara@ufl.edu
University of Florida

Behzad Aghdashi
saghdashi@ufl.edu
University of Florida

Tom Creasey
tom@caliper.com
Caliper Corporation

UF | Transportation Institute UNIVERSITY of FLORIDA | McTrans

Analyzing Corridors and Systems with the Highway Capacity Manual

Presenters:

Lily Elefteriadou, Ph.D

Fabio Sasahara, Ph.D.

Behzad Aghdashi, Ph.D.

March 25, 2021

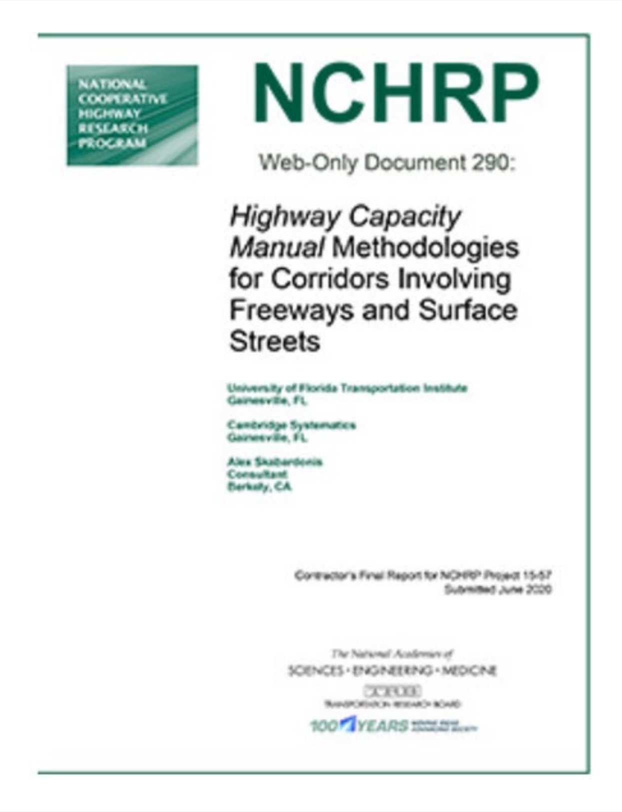
Introduction

Background:

Based on NCHRP 15-57
“Highway Capacity Manual Methodologies for Corridors Involving Freeways and Surface Streets”

NCHRP Web-Only Document 290, July 2020
http://www.trb.org/main/blurbs/181364.aspx

HCM: New Chapter 38 – Network Analysis

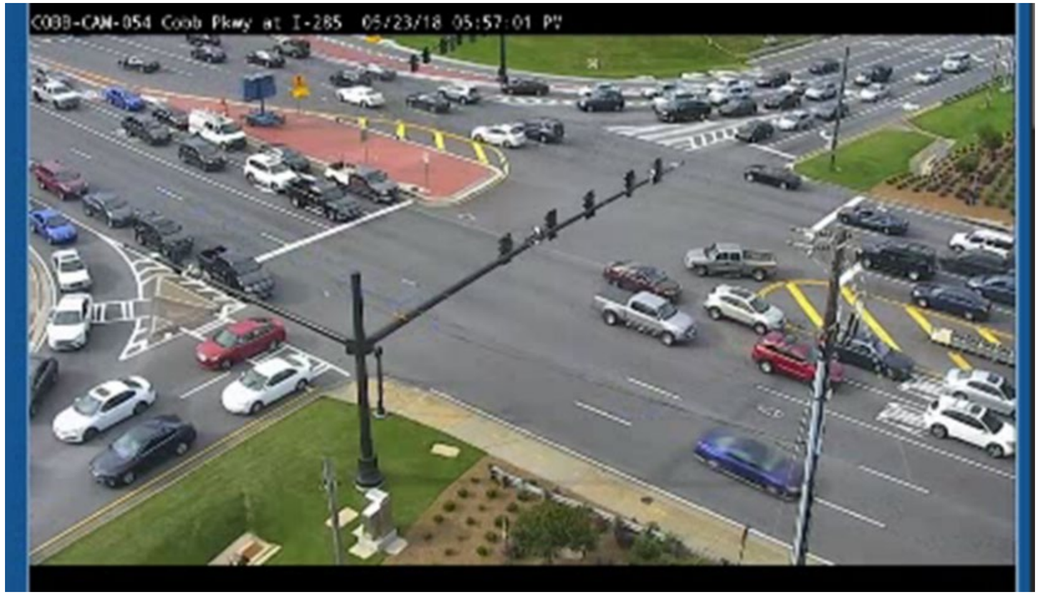


Traditionally, the HCM has:

- Analyzed freeways and arterials separately
- Ignored spillback effects from one facility type to another
- Used different performance measures for different facility types

Now, the new network analysis methods can:

- Evaluate spillback
- Estimate travel time across facilities
- Conduct lane-by-lane analysis for freeways



Performance measurement for network analysis

Current HCM performance measurement framework

Freeway Segments	
Density (pc/mi)	

Signalized Intersections	Unsignalized Intersections
Control delay (s)	Control delay (s)

Urban streets facilities	Unsignalized Intersections
Speed	Experienced travel time (s)

Network-based measures

O-D-based measures

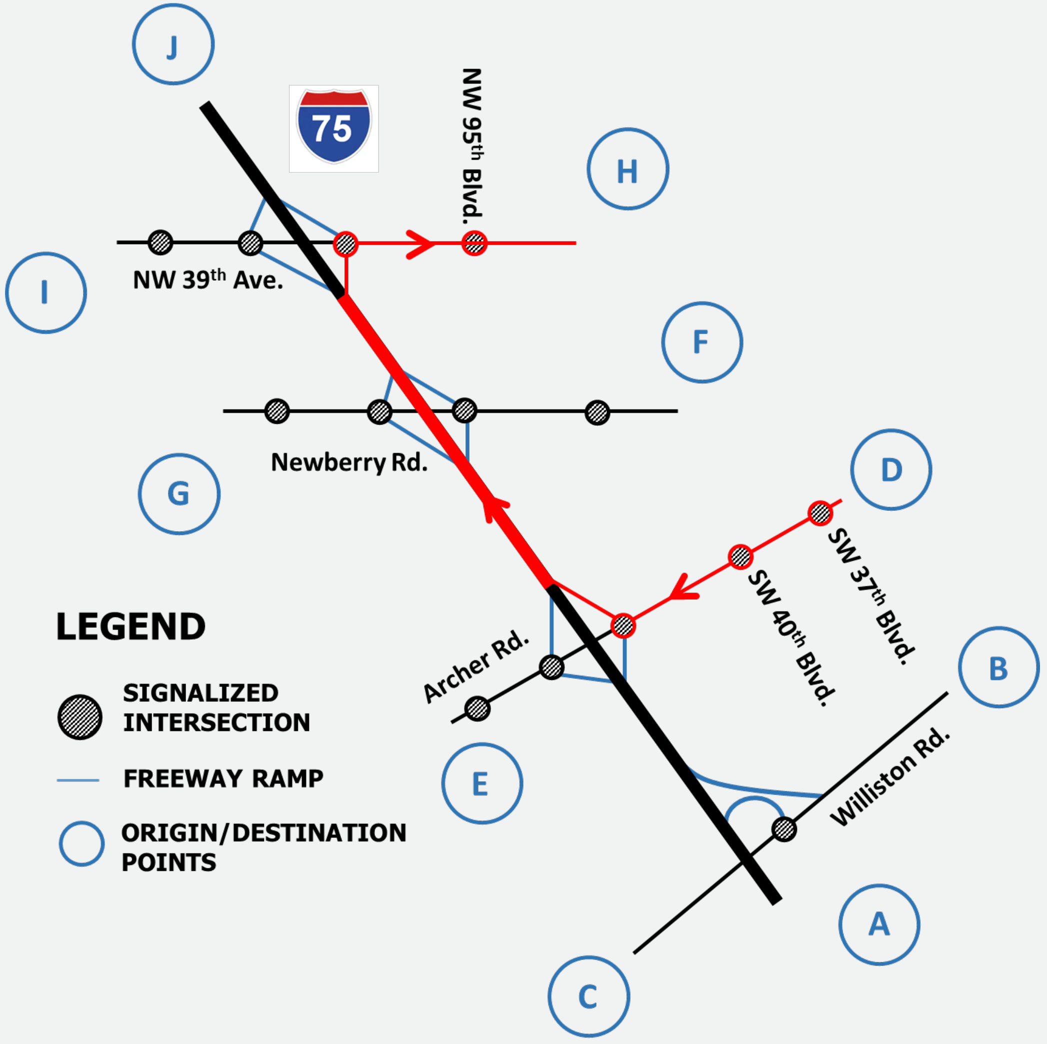
New approach:

Travel Time as a common performance measure

Origin – Destination (O-D) Analysis

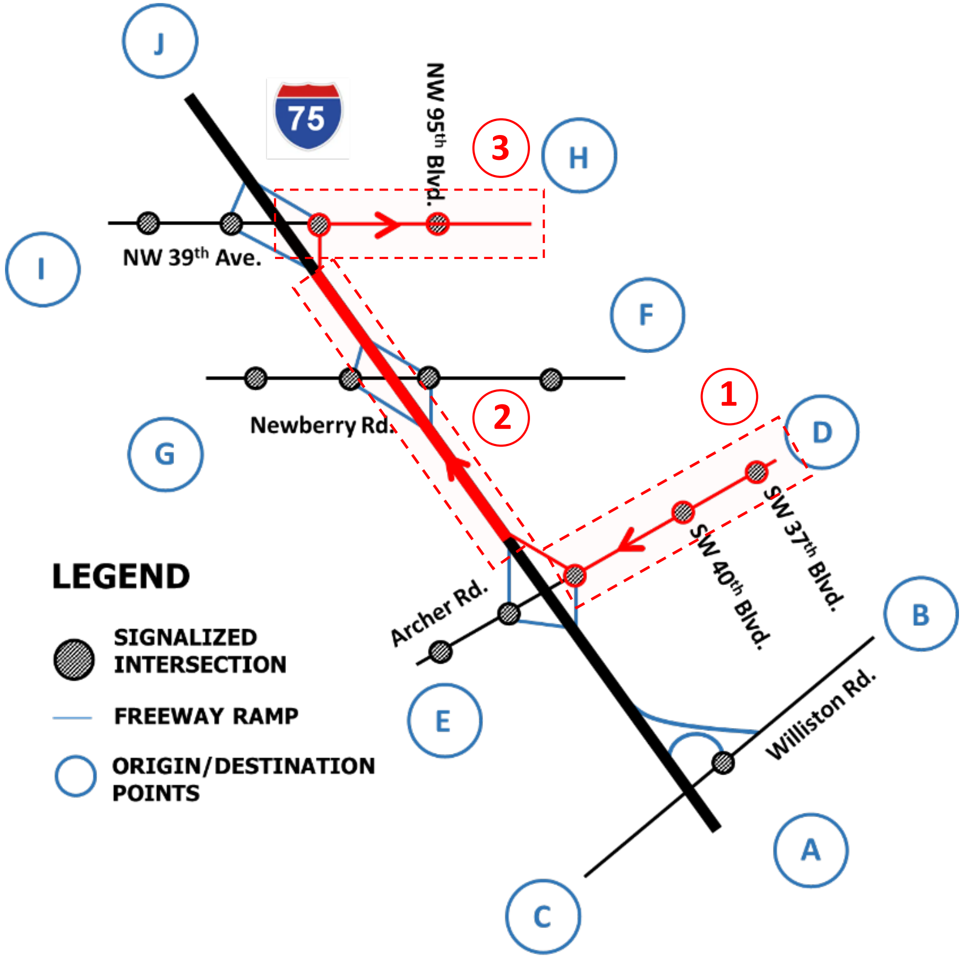
Performance estimates obtained for each origin-destination pair

Example: From Origin D to Destination H

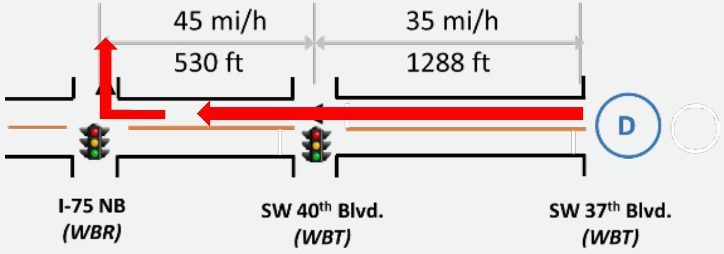


Sample network analysis (Gainesville/FL)

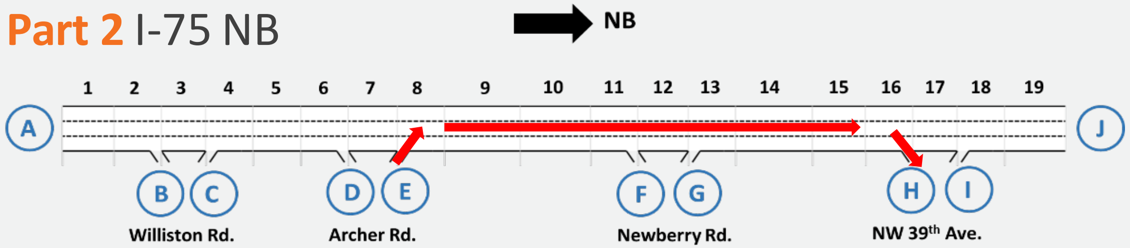
From Origin D to Destination H



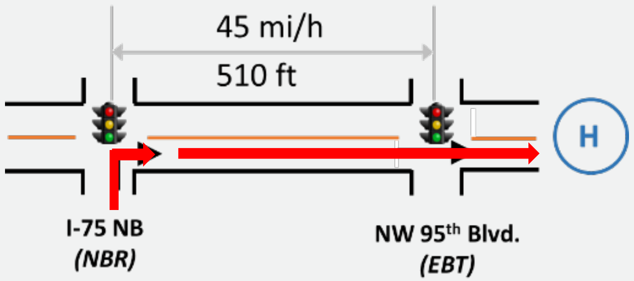
Part 1 Archer Rd WB.



Part 2 I-75 NB

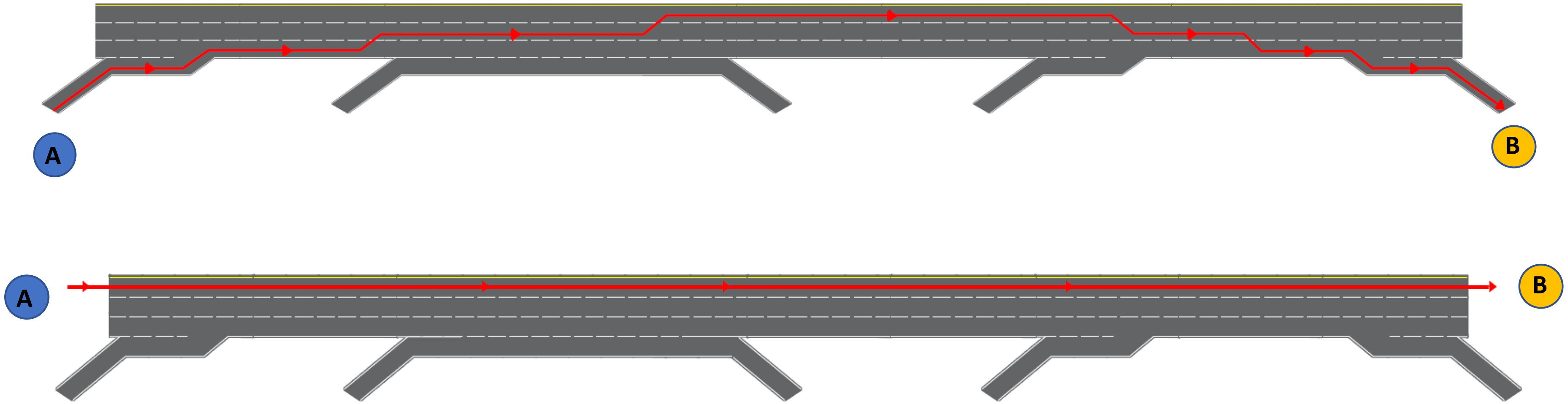


Part 3 NW 39th Ave. EB.

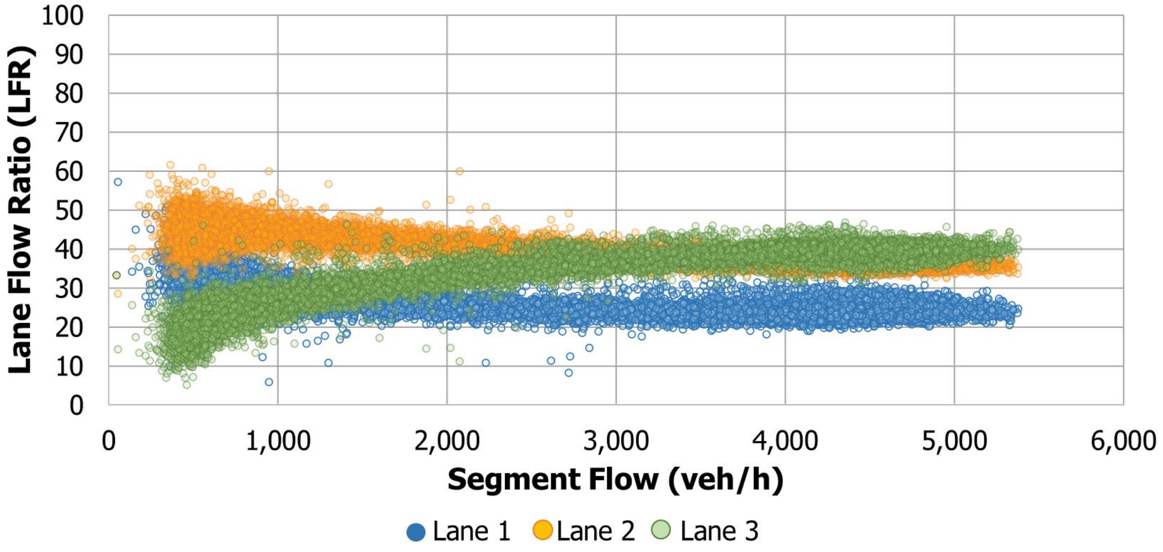


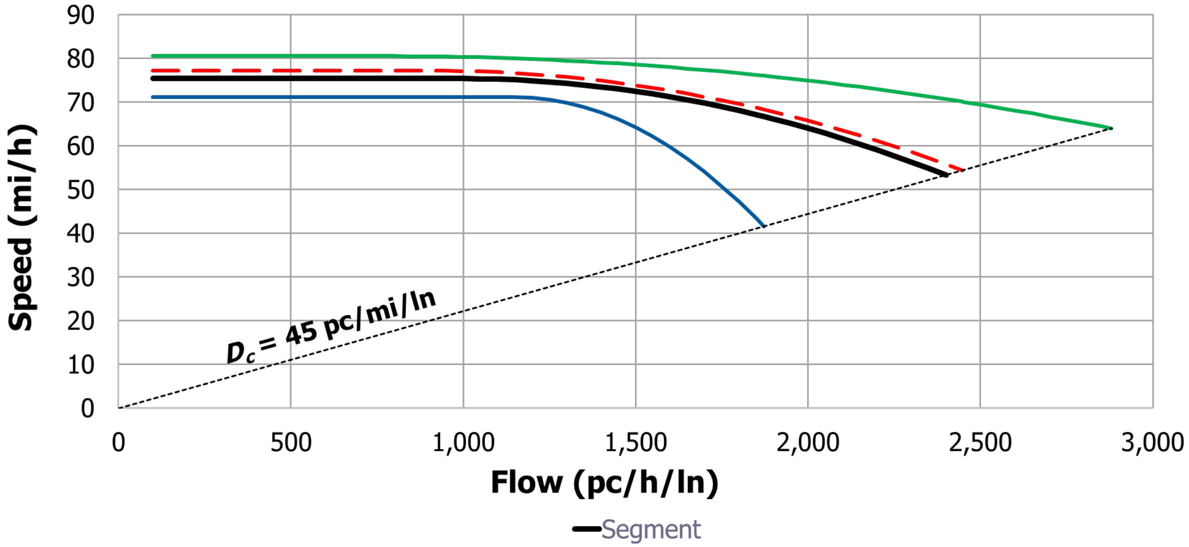
Estimating travel times along the freeway facility

- Speeds vary among freeway lanes
- Lane selection is a function of the O-D
- Each O-D selects a lane with a certain probability



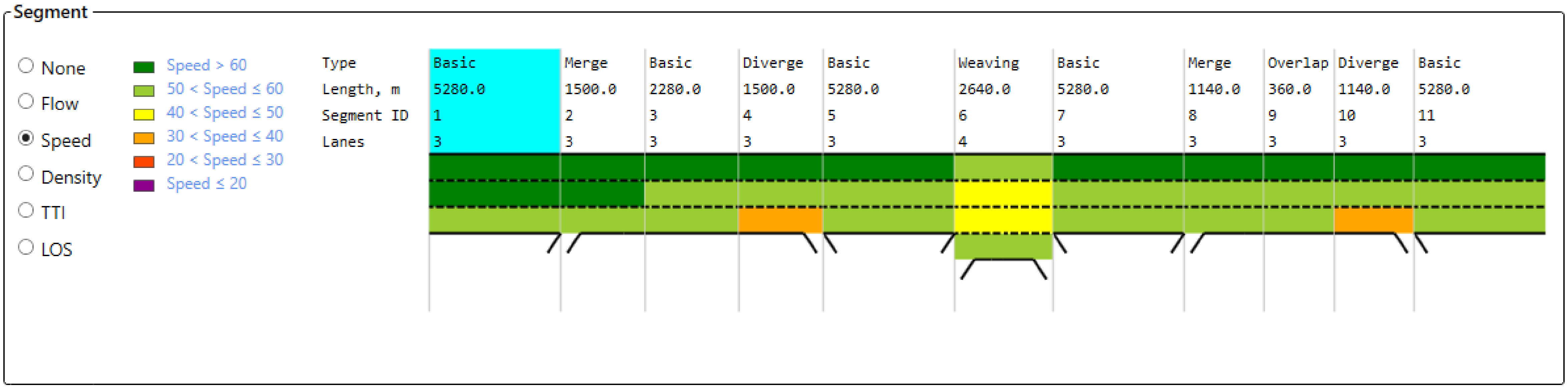
Lane-by-lane performance along the freeway





Lane 1 Lane 2 Lane 3

For freeways, new method estimates speed by lane



Computing the O-D Travel Time:

- Sum of travel times for all traveled segments
- If trip longer than the 15-min analysis period (900 s) → consider multi-period

Segment ID	Segment travel time (s)		Cumulative travel time (s)	Active time period	Selected travel time (s)
	Time Period 1	Time Period 2			
1	**34**	28	34	TP 1	34
2	**26**	29	60	TP1	26
3	**73**	86	133	TP1	73
4	**345**	390	478	TP1	345
5	**185**	195	663	TP1	185
6	**310**	359	973	TP1	310
7	240	**240**	1213	TP2	240
8	120	**122**	1335	TP2	122
9	20	**18**	1353	TP2	18
10	45	**53**	1406	TP2	53
	Total travel time (s):		**1406**		

Freeways Lane-by-Lane Analysis

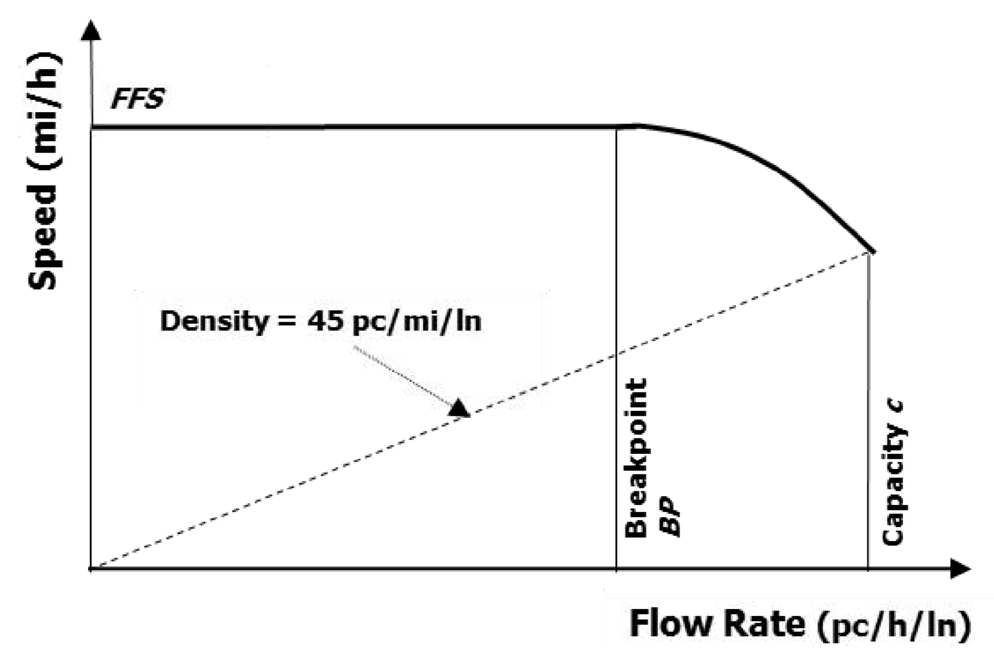
Estimation of Flow Distribution by Lane

- LFR (Lane Flow Ratio) = % of total segment flow assigned to each lane
- Different inputs for different segment types

	Basic	Merge/Diverge	Weaving
Mainline demand flow rate	✓	✓	✓
% Heavy vehicles	✓	✓	✓
% Grade	✓	✓	✓
Nearby ramps	✓	✓	
Ramp demand flow rate		✓	✓
Volume Ratio (weaving volume / total volume)			✓
Weaving Length (L_s)			✓
Interchange Density (ID)			✓

Estimation of Speeds by Lane

Lane by lane model built over existing HCM speed-flow models:



$$S_i = FFS_i \qquad \text{if } v_i \leq BP_i$$

$$S_i = FFS_i - \frac{\left(FFS_i - \frac{c_i}{45}\right)(v_i - BP_i)^2}{(c_i - BP_i)^2} \qquad \text{if } v_i > BP_i$$

S_i = speed in lane *i* (mi/h);
FFS_i = free-flow speed for lane *i* (mi/h);
c_i = capacity of lane *i* (pc/h/ln);
v_i = demand flow rate for lane *i* (pc/h/ln);
BP_i = breakpoint value for lane *i* (pc/h/ln)

How are capacities and free-flow speed (FFS) provided on a lane-by-lane basis?

New models developed to estimate lane-by-lane capacity and speed for freeway segments

No additional inputs required from the user

Segment type	Number of lanes	FFS Multiplier			
		L1	L2	L3	L4
Basic	2 lanes	0.965	1.032		
	3 lanes	0.934	1.01	1.087	
	4 lanes	0.924	0.989	1.028	1.079
Merge	2 lanes	0.964	1.044		
	3 lanes	0.955	1.015	1.045	
	4 lanes	0.935	0.991	1.036	1.091
Diverge	2 lanes	0.961	1.035		
	3 lanes	0.943	1.024	1.068	
	4 lanes	0.933	0.975	1.018	1.074

Free-Flow Speed distribution

Segment type	Number of lanes	Capacity			
		L1	L2	L3	L4
Basic	2 lanes	0.44	0.56		
	3 lanes	0.25	0.35	0.40	
	4 lanes	0.19	0.25	0.28	0.28
Merge	2 lanes	0.42	0.58		
	3 lanes	0.23	0.36	0.41	
	4 lanes	0.21	0.24	0.25	0.30
Diverge	2 lanes	0.42	0.58		
	3 lanes	0.26	0.34	0.40	
	4 lanes	0.21	0.24	0.27	0.28

Capacity distribution

Queue Spillback Analysis

Adjustments to predicted performance due to spillback

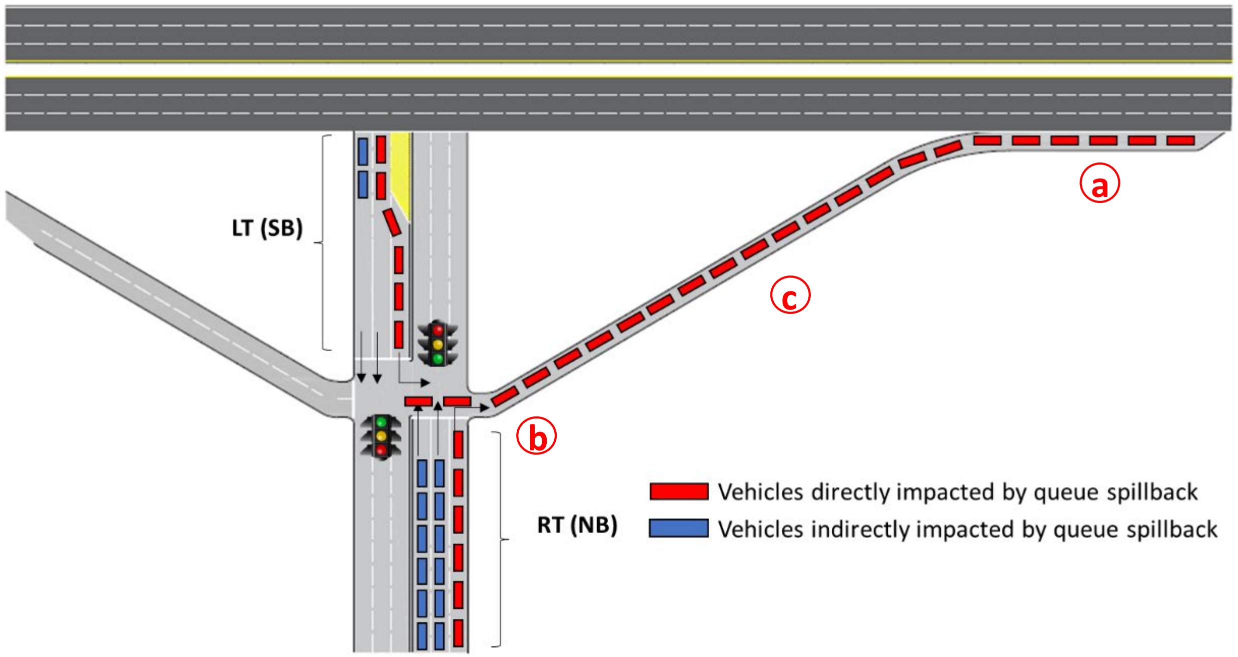
Spillback from on-ramp

Spillback from off-ramp

Spillback from on-ramp

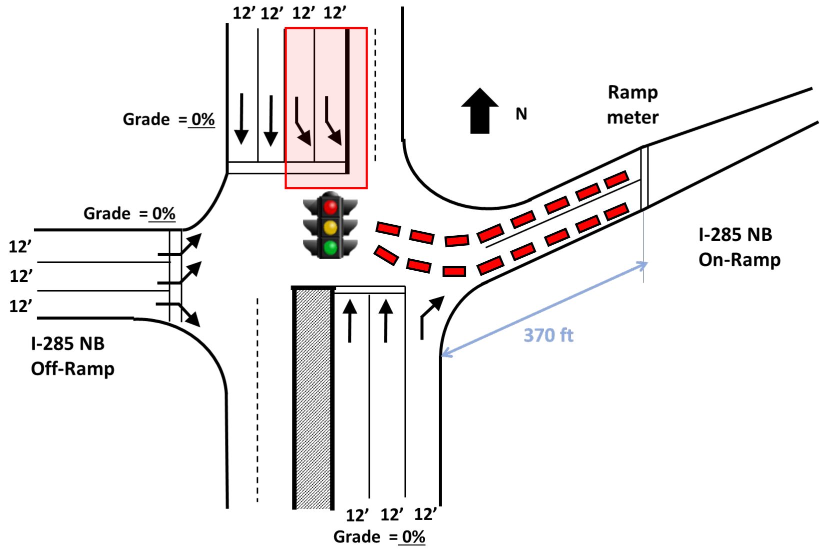
Occurs when two conditions are met:

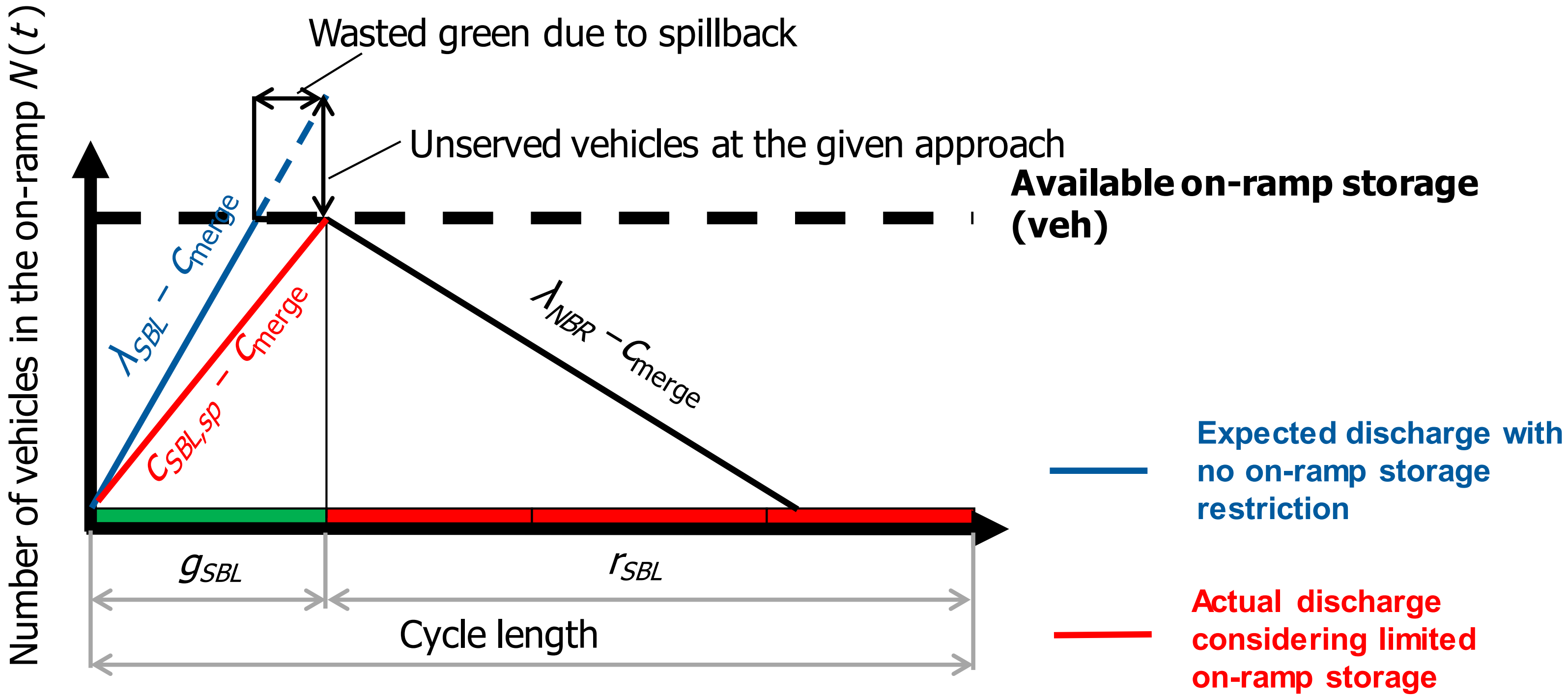
- Insufficient capacity at
    - a) freeway merge,
    - b) ramp roadway or
    - c) ramp meter; AND
- Insufficient storage length at the on-ramp;



Spillback analysis - signalized intersections

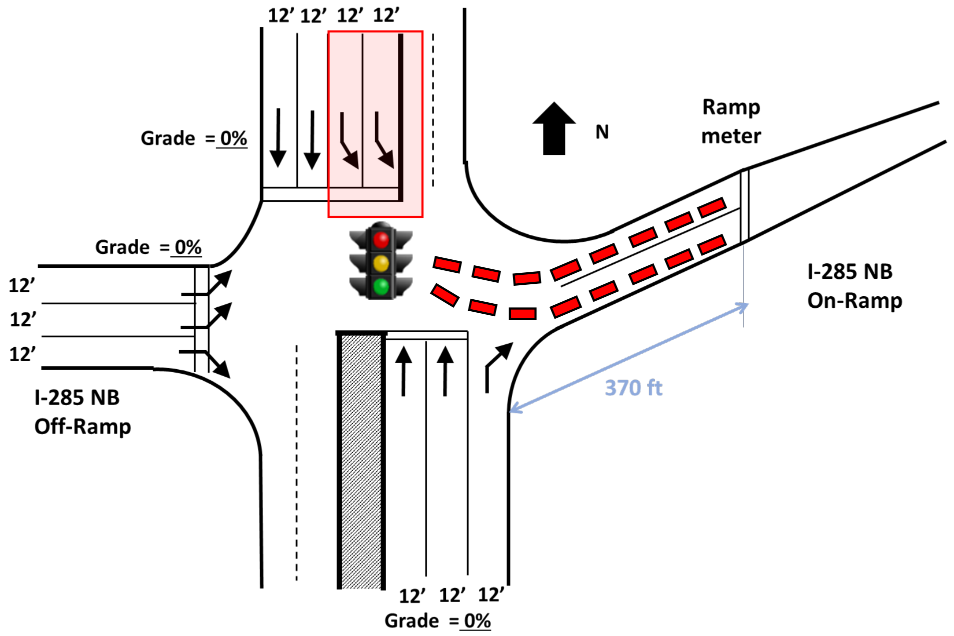
- Queues are modeled at the on-ramp for every cycle
- Number of vehicles at the on-ramp cannot exceed the maximum storage
- Reduced capacity is computed based on the maximum throughput

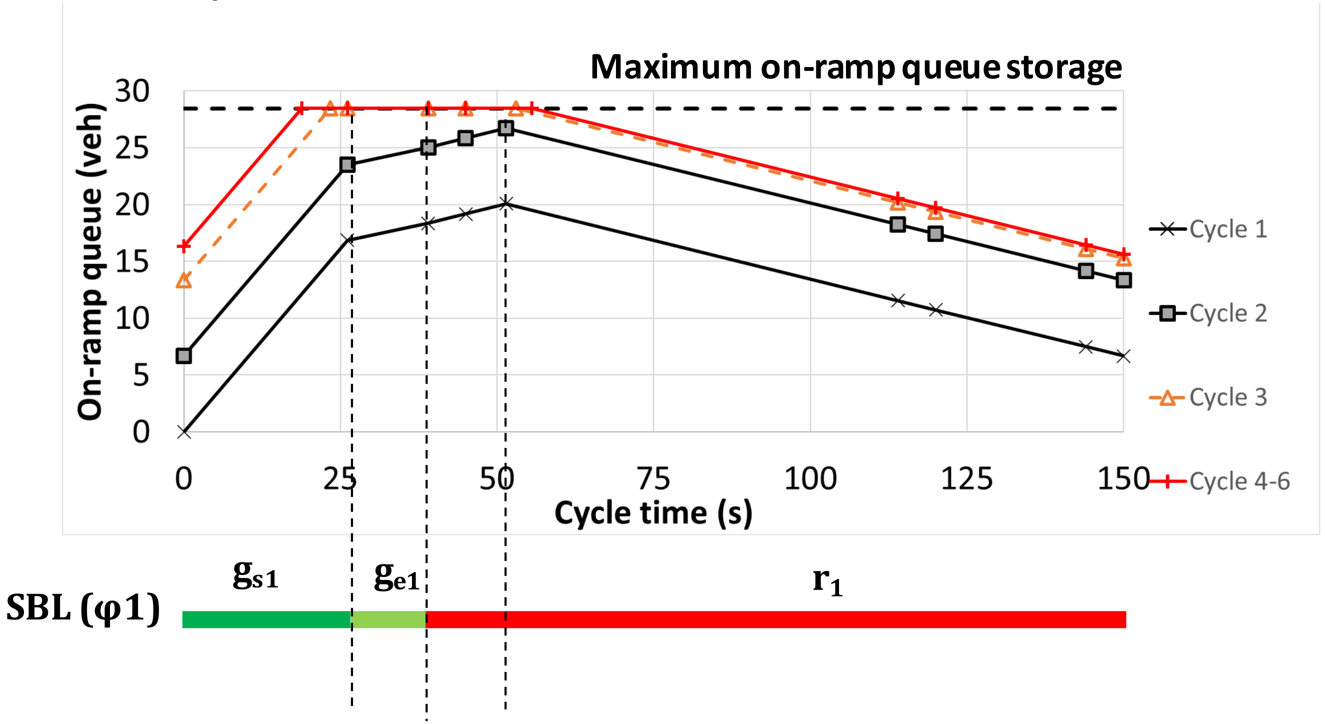




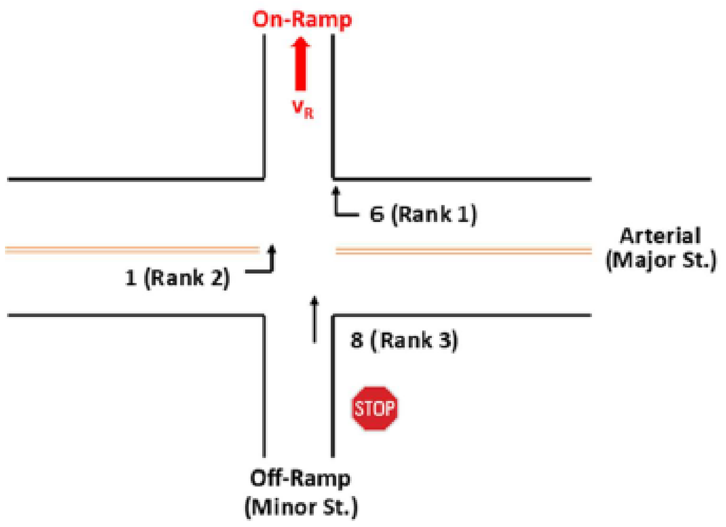
Spillback analysis - signalized intersections

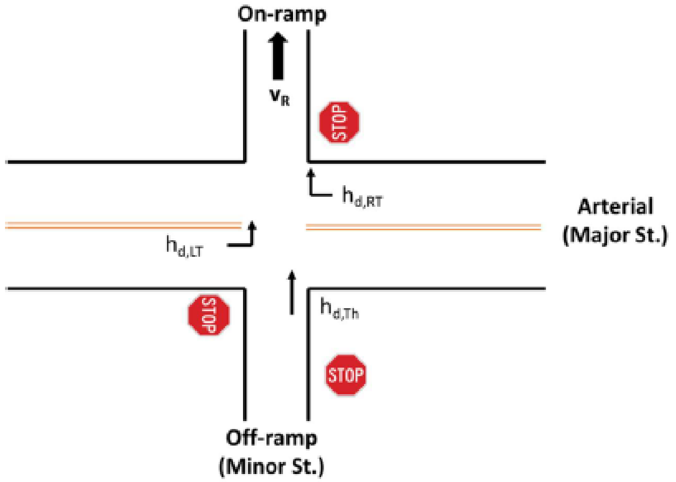
A combined queue polygon is developed for every movement:

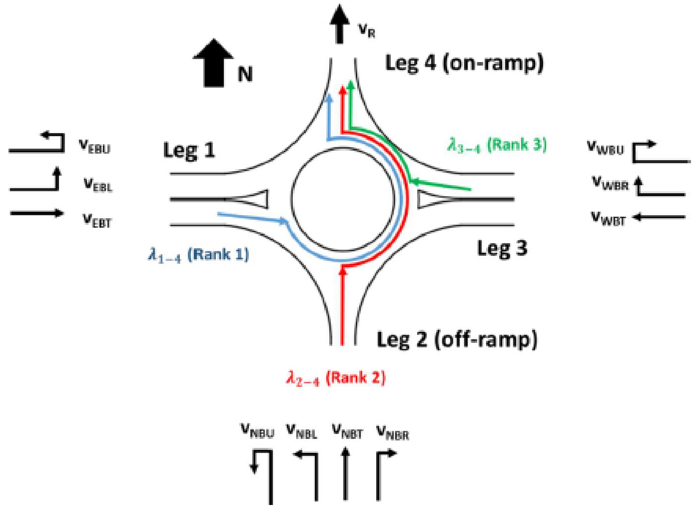




Spillback analysis considers stop-controlled intersections and roundabouts, based on existing HCM methods



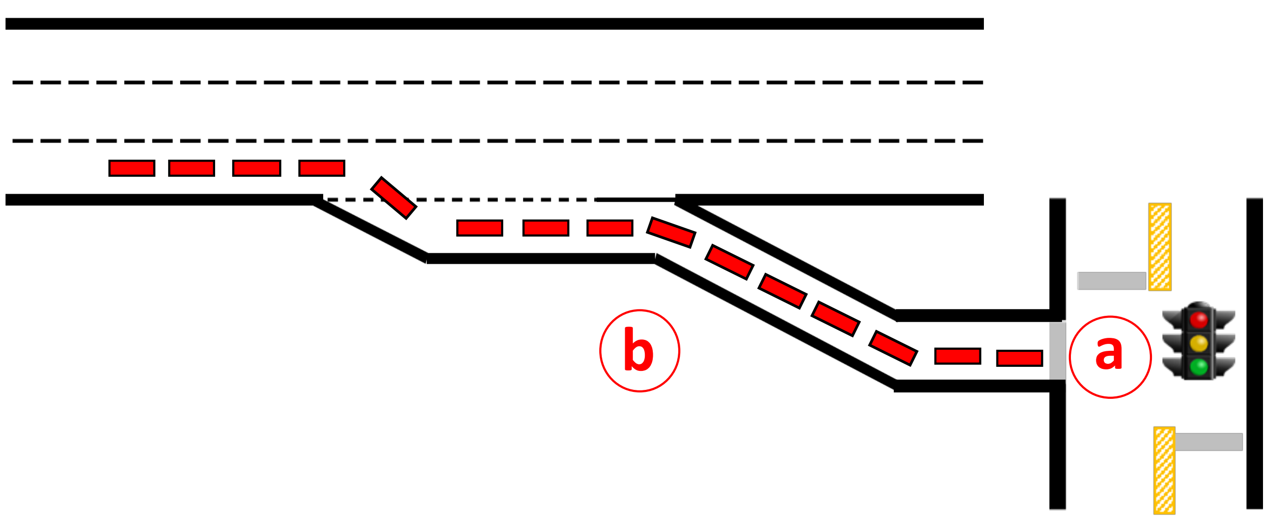




Spillback from off-ramp

Occurs when two conditions are met:

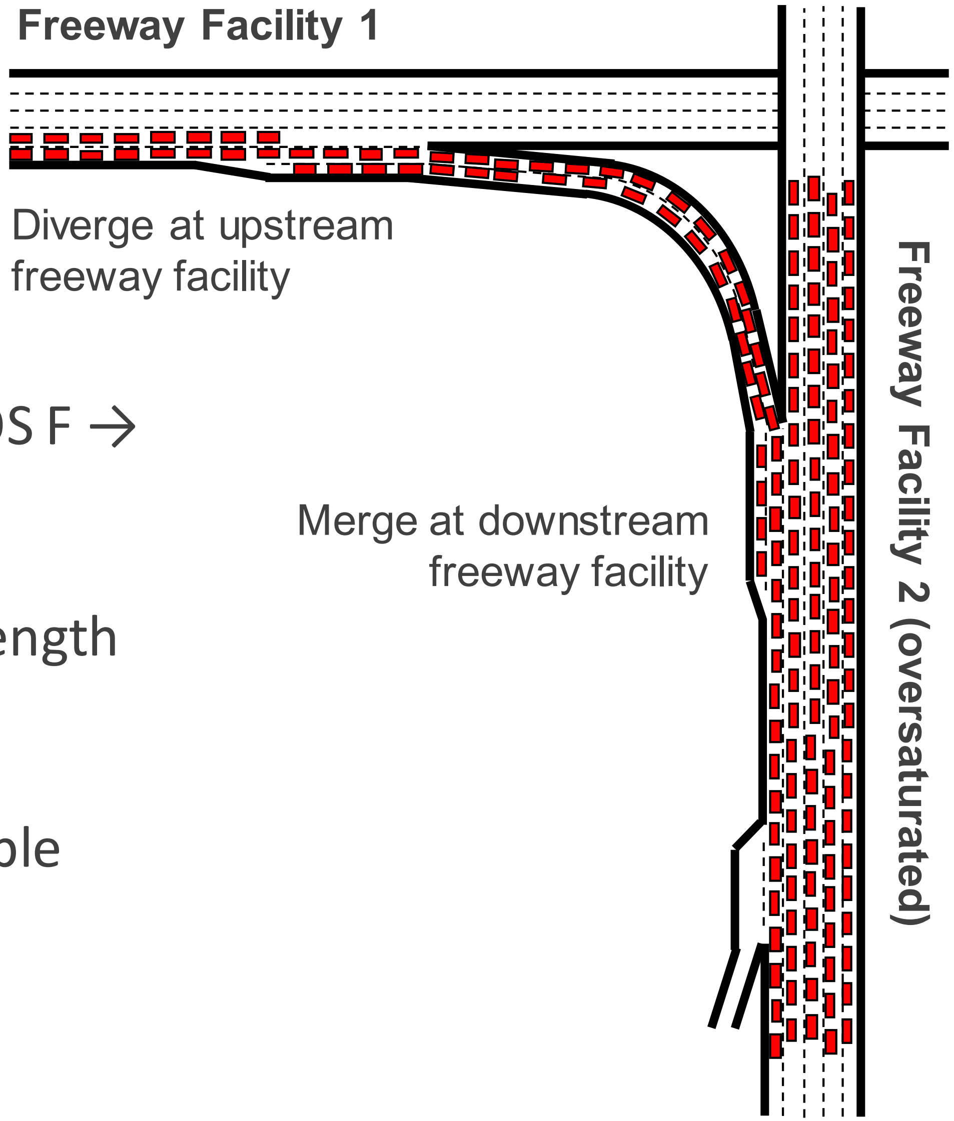
- Insufficient capacity at
  - a) downstream ramp terminal (intersection) or
  - b) ramp roadway; AND
- Insufficient storage length;



Spillback from off-ramp

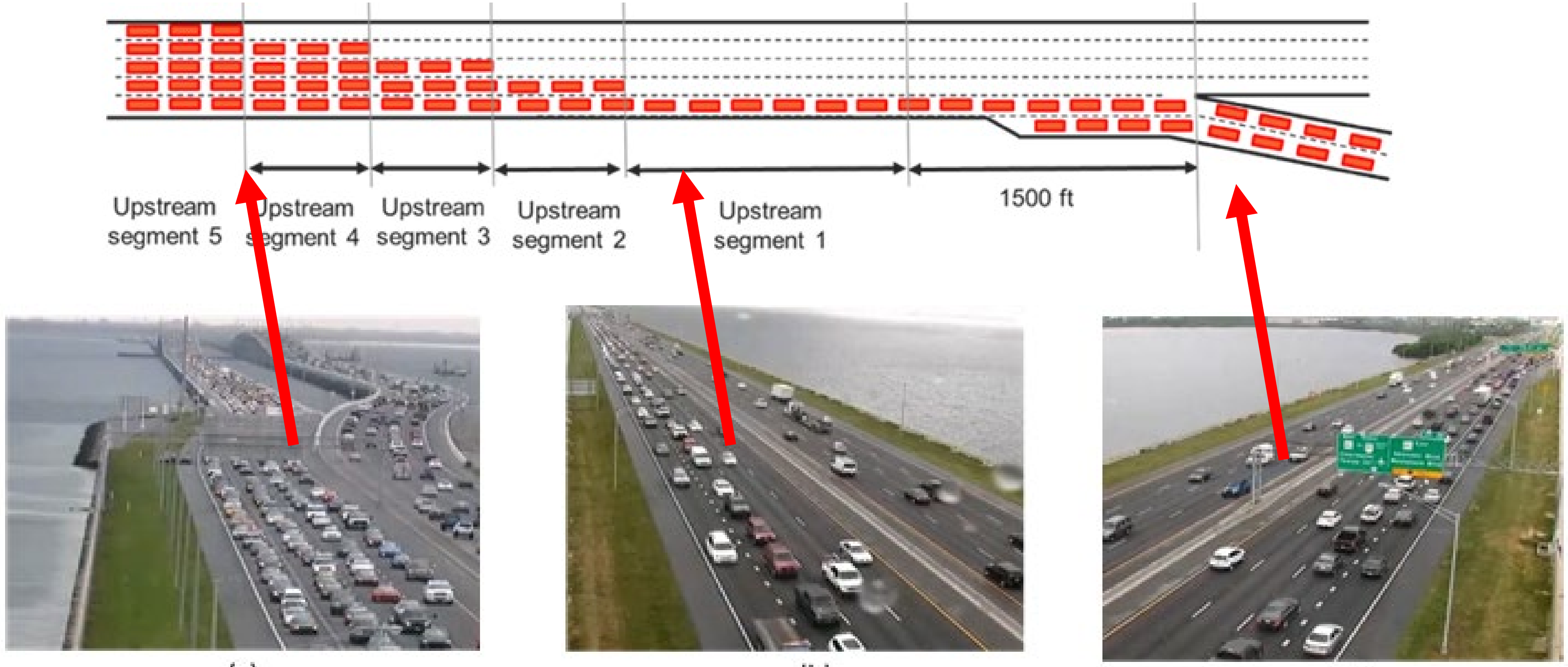
Freeway-to-freeway queue spillback

- Downstream freeway facility operates at LOS F → HCM Freeway Facilities Oversaturated methodology to estimate on-ramp queue length
- Check on-ramp queue length against available storage at the ramp



Spillback from off-ramp

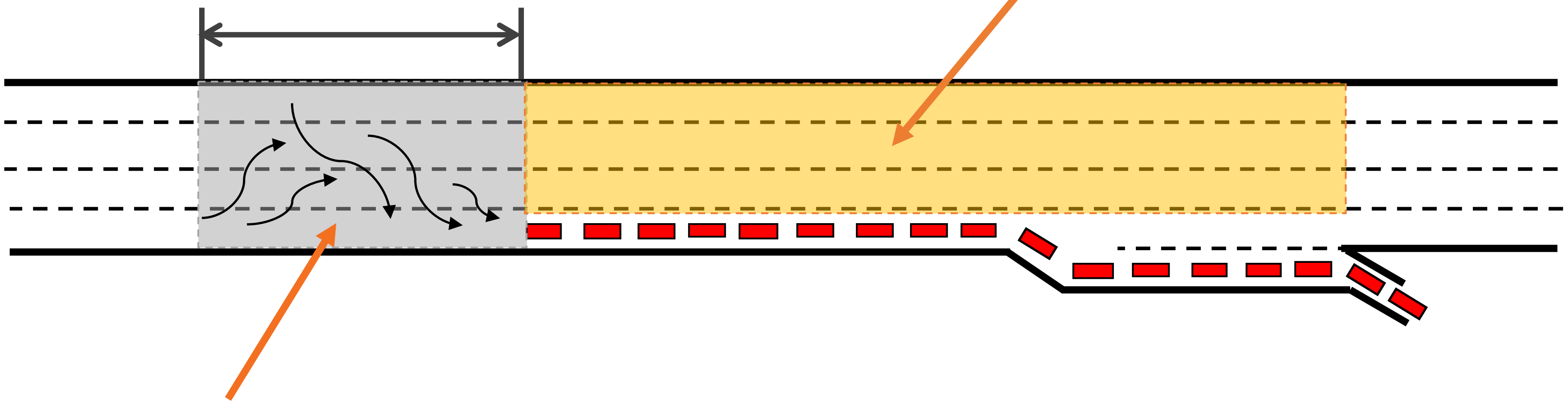
Freeway impact is more localized close to exit and spreads upstream



(c) (b) (a)

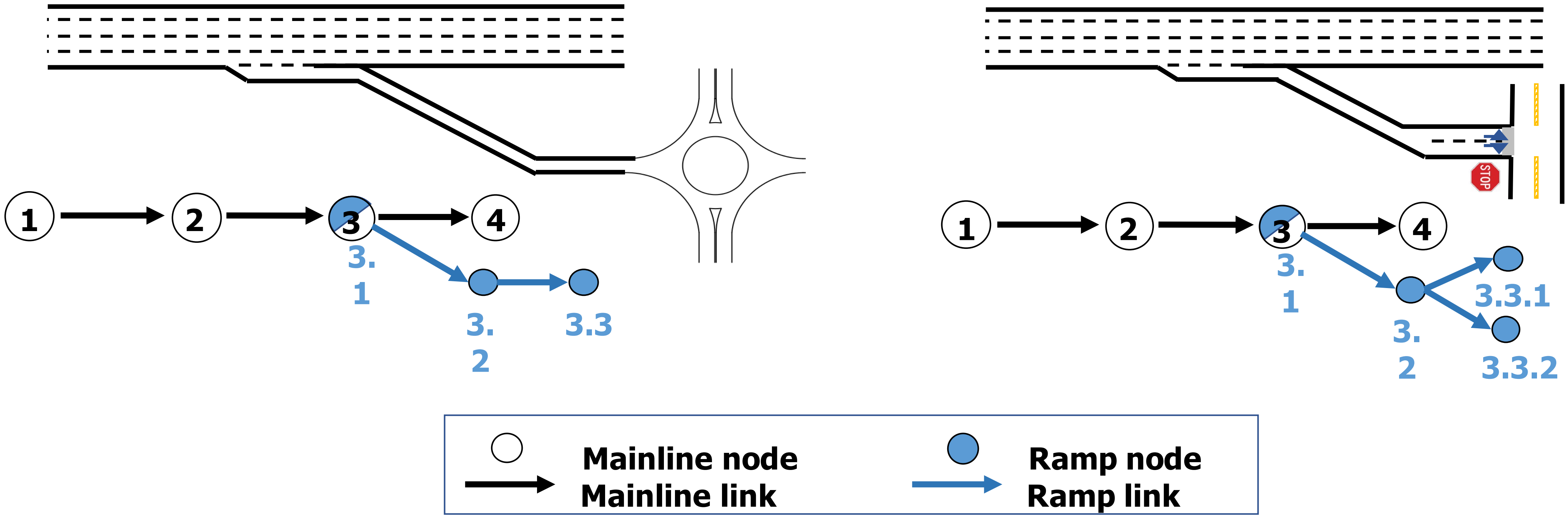
Spillback from off-ramp

- Extension of Chapter 25 – Freeway Facilities Oversaturated methodology
- Capacity Adjustment Factors to model queue spillback impacts



Spillback from off-ramp

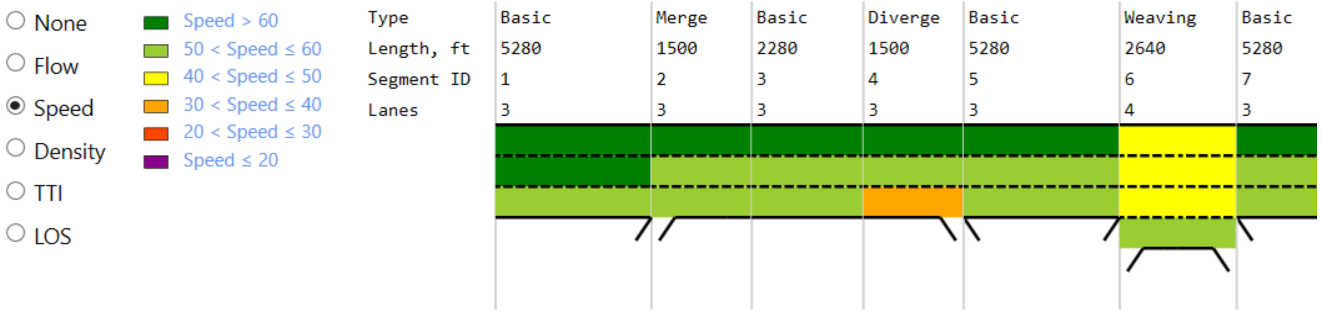
- Node-link structure extended to address ramp roadway and ramp terminal
- Intersection lanes analyzed independently

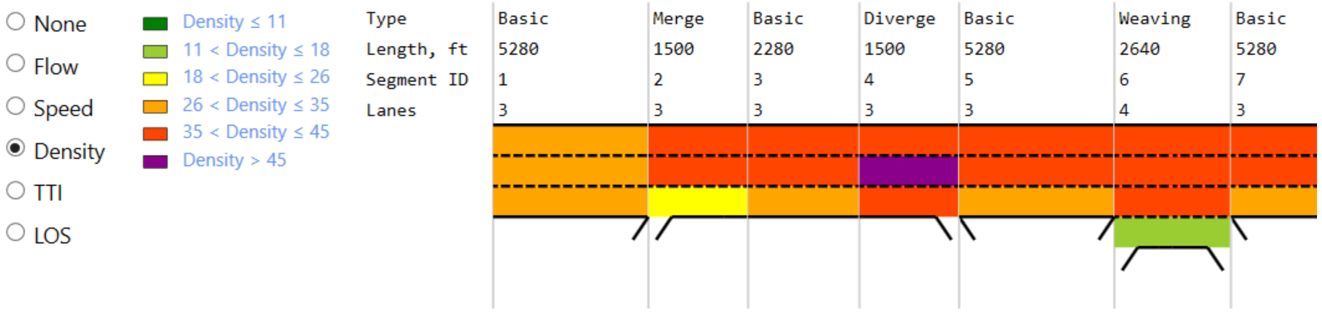


Implementation in HCS

Implementation in HCS

The proposed methodologies in NCHRP 15-57 are implemented in the Highway Capacity Software (HCS).





Network Analysis in the HCS

Arterial(s) and freeway(s) can be modeled in the HCS independently. Then, the two are connected to construct the network.

Load Freeway Facility | Create Freeway Facility | Time Periods List 1

I-75_NB_Gainesville.xuf

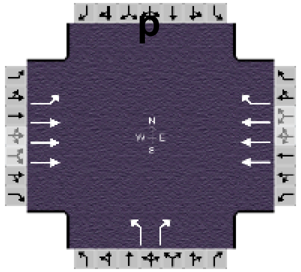
Segment	Segment Type	File	File Name	Node	Approach	On-Ramp Flow Rate (veh/h)	Total Queue Storage (ft)	Approach Queue (veh)	RQ
2	Off-Ramp	Select	Williston.xus	2	SB	-	1000	31.9	0.80
4	On-Ramp	Select	Williston.xus	2	SB	535	1100	0.0	0.00
6	Off-Ramp	Select	Archer.xus	2	NB	-	1000	11.8	0.30
8	On-Ramp	Select	Archer.xus	2	SB	361	2250	0.0	0.00
11	Off-Ramp	Select	Newberry.xus	2	NB	-	1600	14.3	0.22
13	On-Ramp	Select	Newberry.xus	2	SB	441	1850	0.0	0.00
16	Off-Ramp	Select	39th.xus	2	NB	-	1200	14.7	0.31
18	On-Ramp	Select	39th.xus	2	SB	145	2200	0.0	0.00

PRIMARY INPUT DATA

General

Urban Street	SW Archer Road		
Intersection	I-75 NB On-/Off-Ramp		
Description			
Forward Direction	EB	Area Type	Other
Segment Length, ft	840	Duration	0.25
All Segment Lengths		PHF	1.00

Onramp



Off-ramp

For ramp segments, select the connecting arterial intersection (or freeway) file

Select the corresponding node (if the arterial network has multiple intersections) and connecting approach

Network Analysis in the HCS

- Travel Times by O-D implemented in Freeways

START GENERAL SEGMENTS DETAILS RESULTS REPORT

Facility Overall Results

Space Mean Speed, mi/h	50.3	Density, veh/mi/ln	35.9
Average Travel Time, min	7.20	Density, pc/mi/ln	36.7

OD Results

ID	OD	T1	T2	T3	T4	T5
1	1(Basic) -> 4(OffRamp)	130.58	131.29	132.13	130.67	123.77
2	1(Basic) -> 6(Weaving)	217.68	219.27	221.78	217.83	214.72
3	1(Basic) -> 10(OffRamp)	313.28	316.72	322.52	314.17	301.43
4	1(Basic) -> 11(Basic)	372.73	376.75	384.13	373.56	364.16
5	2(OnRamp) -> 4(OffRamp)	67.85	68.49	69.25	67.92	61.11
6	2(OnRamp) -> 6(Weaving)	154.95	156.46	158.90	155.08	152.07
7	2(OnRamp) -> 10(OffRamp)	250.55	253.91	259.63	251.41	238.78
8	2(OnRamp) -> 11(Basic)	310.00	313.94	321.25	310.80	301.51
9	6(Weaving) -> 6(Weaving)	38.54	39.65	74.65	87.35	35.71
10	6(Weaving) -> 10(OffRamp)	129.28	131.64	134.34	129.03	121.36
11	6(Weaving) -> 11(Basic)	188.73	191.66	195.96	188.42	184.09
12	8(OnRamp) -> 10(OffRamp)	36.97	37.81	38.43	36.86	30.05
13	8(OnRamp) -> 11(Basic)	96.42	97.83	100.05	96.25	92.78

Messages

Back

Queue Spillback Analysis in the HCS

- Off-ramp spillback check implemented in Freeway Facilities

Spillback Results

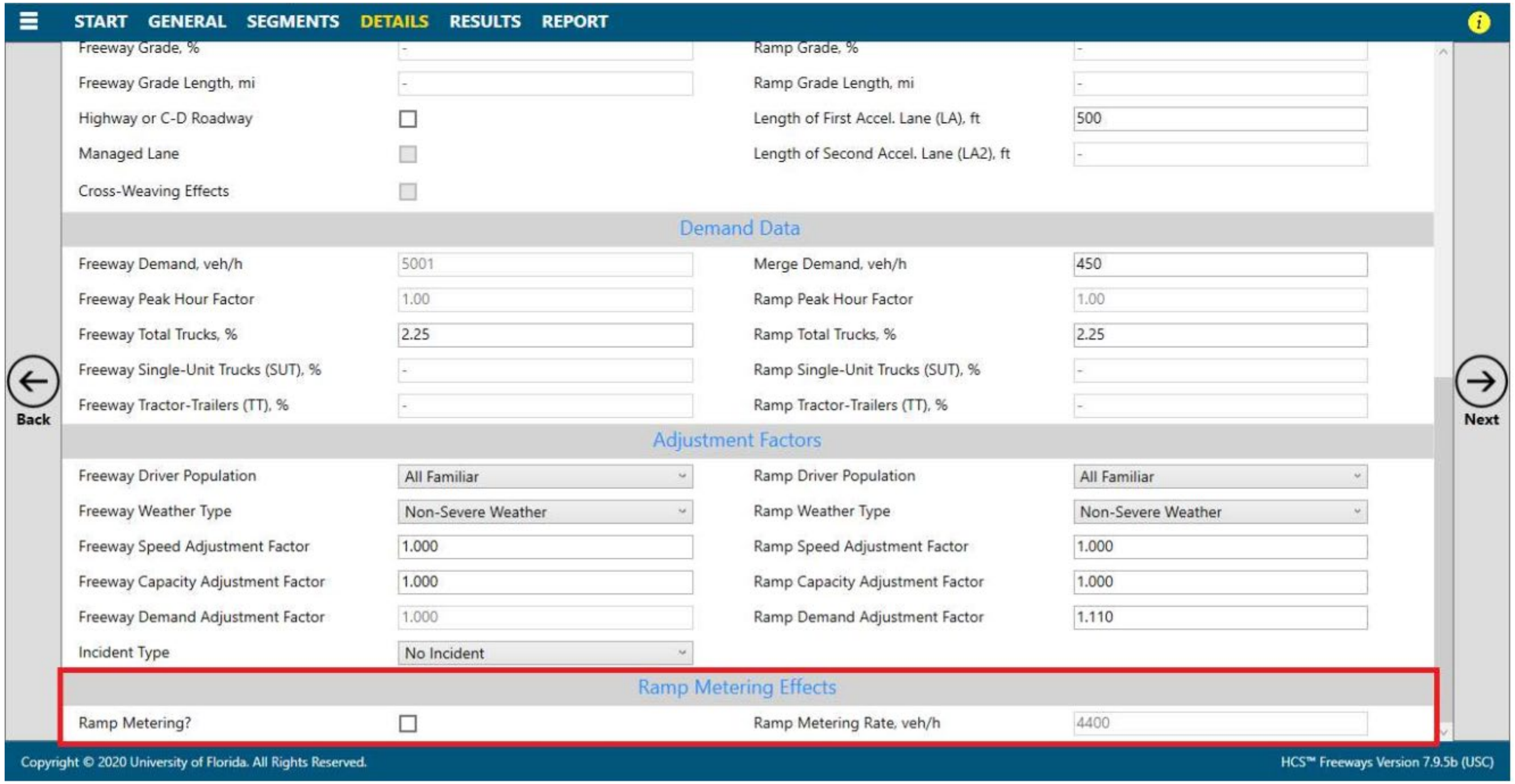
Regimes	0	Lanes Outside Influence Area, ln	4
Influence Area Lanesln	1	Spillback Lanes, ln	0
Queue Storage Length Ramp Lane (L_A), ft	800	Shoulder Length (L_E), ft	800
Queue Storage Length Lane 1, ft	500	Length of Additional Queue (Q_{SP}), ft	0
Average Vehicle Length (L_H), ft/veh	25.5	Queue Storage Ratio (R_Q)	0.00
Capacity Adjustment Factor Spilback	1.000	Probability of Blockage on Lane 2 (P_B)	0.000
Adjusted Capacity, pc/h	8460	Proportion of Lane 1 Weaving Flow	0.500
Spillback Lanes Flow (V_{SA}), pc/h	965	Influence Area Lanes Flow (V_{IA}), pc/h	2483
Outer Lanes Flow (V_O), pc/h	2483	Spillback Lanes Speed (S_{SA}), mi/h	20.0
Influence Area Lanes Speed (S_{IA}), mi/h	75.0	Outer Lanes Speed (V_O), mi/h	75.0
Average Speed (S), mi/h	46.7	Average Density (D), pc/mi/ln	31.7
LOS	D		

Lane-by-Lane Results

Lane	FFS	Capacity (veh/h)	Flow (veh/h)	BP (veh/h)	Speed mi/h	Travel Time (s)
1	54.6	2069	360	1776	54.6	32.97
2	59.3	2069	2069	1593	47.0	38.30
3	63.2	2069	2069	1441	47.0	38.30
4	60.0	2069	1209	1565	60.0	30.00

Queue Spillback Analysis in the HCS

- User input for Ramp Metering Rate (on-ramp spillback analysis)



Queue Spillback Analysis in the HCS

- Roundabout on-ramp queue spillback analysis

Roundabout ramp terminals – geometry input

Queue Spillback Analysis in the HCS

- Roundabout on-ramp queue spillback analysis

On-Ramp Computations and Spillback Checks												
Approach	EB			WB			NB			SB		
Lane	Left	Thru.	Right	Left	Thru.	Right	Left	Thru	Right	Left	Thru.	Right
On-Ramp Lanes				1								
Ramp Metering Rate (c_{RM}), pc/h				800								
Ramp Metering Capacity ($c_{R,pce}$), pc/h				800								
Throughput per Approach ($\lambda_{[illegible]}$), pc/h				100	500	634						
Maximum Throughput (λ_{pce}), pc/h				1234								
Ramp Storage Length (L_{ONR}), pc				66								
Queue Storage Ratio (R_Q)				1.64								
Spillback Occurs				Yes								
Queue due to Ramp Spillback, pc				42								
Spillback per Approach ($\lambda_{[illegible]}$), pc/h				4	23	142						
Additional Delay due to On-Ramp Spillback (d_{sp}), s/veh				747.95								
Total Average Delay per Approach (d), s/veh				65.05	317.61	1019.01						

Roundabout ramp terminals – queue spillback results

Questions?

Lily Elefteriadou
elefter@ce.ufl.edu
UF | Transportation Institute UNIVERSITY of FLORIDA

Fabio Sasahara
fsasahara@ufl.edu
UF | Transportation Institute UNIVERSITY of FLORIDA

Behzad Aghdashi
saghdashi@ufl.edu
UF | Transportation Institute UNIVERSITY of FLORIDA

Tom Creasey
tom@caliper.com
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