

What is new in the

# 7<sup>th</sup> Edition of Highway Capacity Manual



Bastian Schroeder,  
ACP40 Chair



Alexandra Kondyli,  
ACP40 Secretary,



Behzad Aghdashi,  
ACP40 Uninterrupted  
Flow SC Chair



Dan Cook,  
ACP40 Interrupted  
Flow SC Chair



Ana Moreno,  
ACP40 Paper  
Review Coordinator



Dave Stanek,  
ACP40 Cross-  
Cutting SC Chair



# Agenda

General Overview of HCM7 – New Methods and Format

Updates to Freeways and Highways – CAVs, 2-Lane, Systems

Changes for Intersections and Arterials – Pedestrians, ATM, CAV

Multimodal Methods and Recent Updates

Case Study Applications

What's next for the HCM

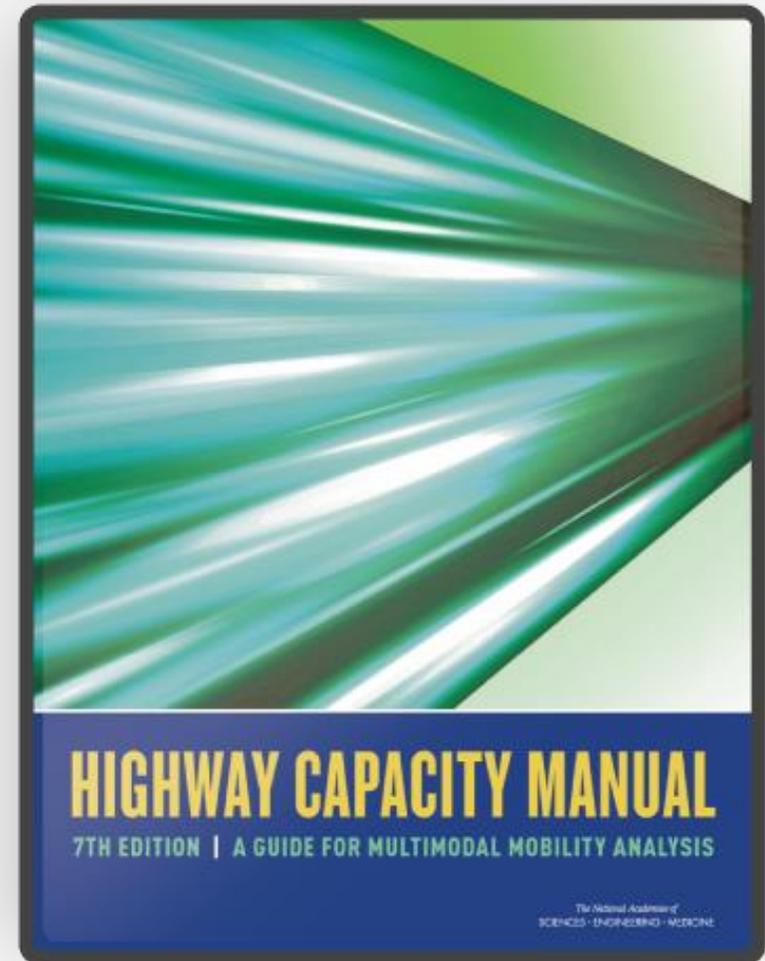


# HCM Overview

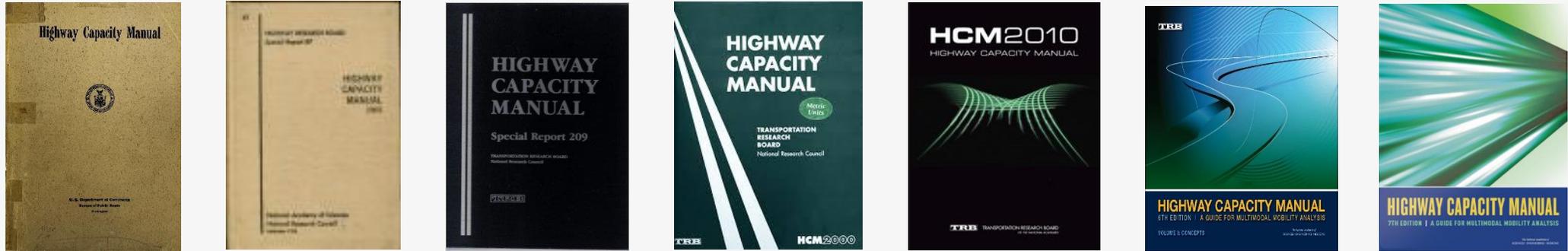
- Overseen by TRB<sup>1</sup> Committee on Highway Capacity and Quality of Service (hcqstrb.org)
- Most methods are developed via national-level projects such as NCHRP<sup>2</sup>.
- Four Volumes:
  - I. Concepts
  - II. Uninterrupted Flow
  - III. Interrupted Flow
  - IV. Applications Guide (Online only)

<sup>1</sup>TRB: Transportation Research Board

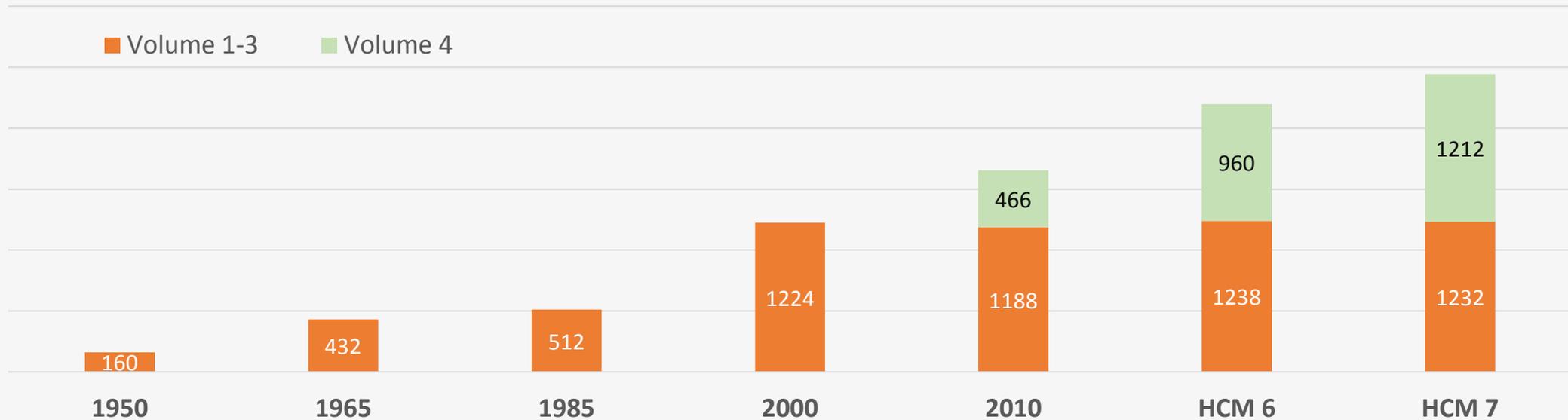
<sup>2</sup>NCHRP: National Cooperative Highway Research Program



# Growth in HCM Content

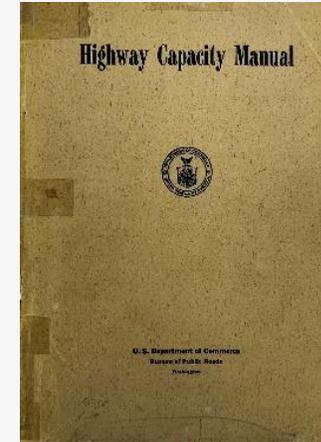


Number of Pages



# History of Major Changes and Updates

- 1950: First document to quantify concept of capacity
- 1965: Introduce LOS concept, bus transit chapter
- 1985: Significant new research, pedestrians, bicycles
  - ✓ 1994 & 1997 updates
- 2000: Divided into multiple parts, new research
  - ✓ Multi-period analysis for freeway facilities
  - ✓ New and updated methodologies for two-lane highways, multilane highways, freeways, traffic signals, and transit
- 2010: Significant new research, four volumes
  - ✓ Multimodal methods integrated in chapters
  - ✓ New methods on ramp terminals, roundabouts, freeway weaving, urban street operations, shared-use paths, and active traffic management
  - ✓ Introduced electronic volume IV
- HCM 6th Edition: Released in 2016
  - ✓ New travel time reliability method
  - ✓ Active travel and demand management (ATDM) and Managed lanes
  - ✓ New methods for work zones, alternative intersections, roundabouts in corridors, and trucks



*A practical guide by which the engineer, having determined the essential facts, can design a new highway or revamp an old one with assurance that the resulting capacity will be as calculated. – 1950 HCM*



## New Research - Updating to HCM 7

Research Project	Project Title	HCM Chapter(s) Updated
<b>NCHRP 17-87</b>	Enhancing Pedestrian Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities	Updated Chapters 18, 19, 20, 30, 31 & 32
<b>FHWA Pooled Fund TPF-5(371)</b>	Capacity Adjustment Factors for Connected and Automated Vehicles (CAV) in the Highway Capacity Manual	Updated Chapter 26, 31 & 33
<b>NCHRP 17-65</b>	Improved Analysis of Two-Lane Highway Capacity and Operational Performance	New Chapter 15
<b>FHWA (FHWA-HOP-16-088)</b>	Active Transportation and Demand Management (ATDM) Analytical Methods for Urban Streets	Updated Chapters 17 & 37
<b>NCHRP 15-57</b>	Highway Capacity Manual Methodologies for Corridors Involving Freeways and Surface Streets	New Chapter 38

Various errata changes and interpretations

## Ongoing/Active Research Impacting Future Releases of HCM

**NCHRP 03-133** Traffic Signal Design and Operations Strategies for Non-Motorized Users

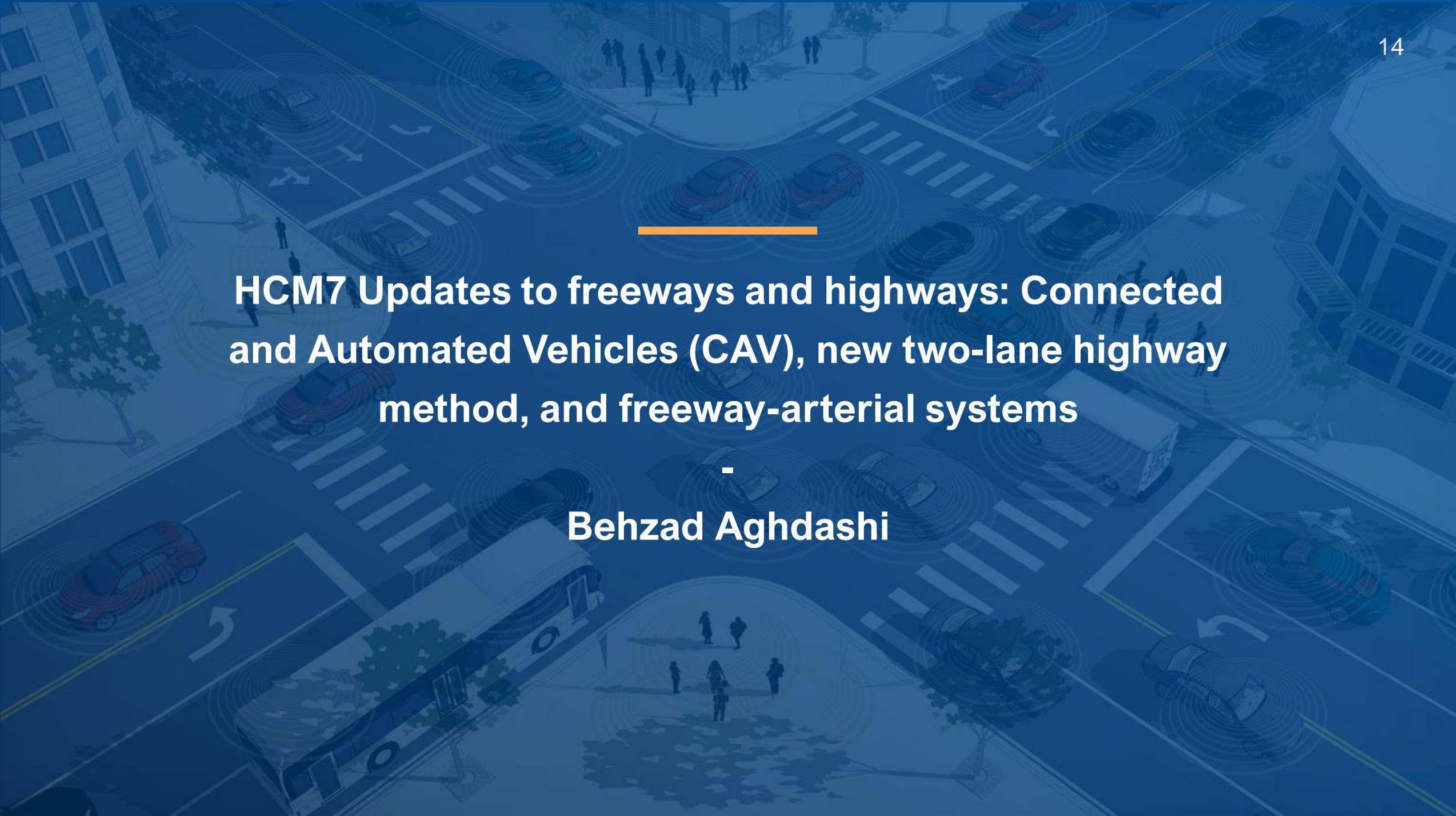
**NCHRP 07-26** Update to HCM Merge, Diverge, and Weaving Methods

**NCHRP 15-66** Arterial Weaving Methodology

**NCHRP 03-130** Guide for Roundabouts

**NCHRP 08-135** Reliability and Quality of Service Evaluation Methods for Rural Highways

**NCHRP 17-98** Guide for Intersection Control Evaluation



---

**HCM7 Updates to freeways and highways: Connected and Automated Vehicles (CAV), new two-lane highway method, and freeway-arterial systems**

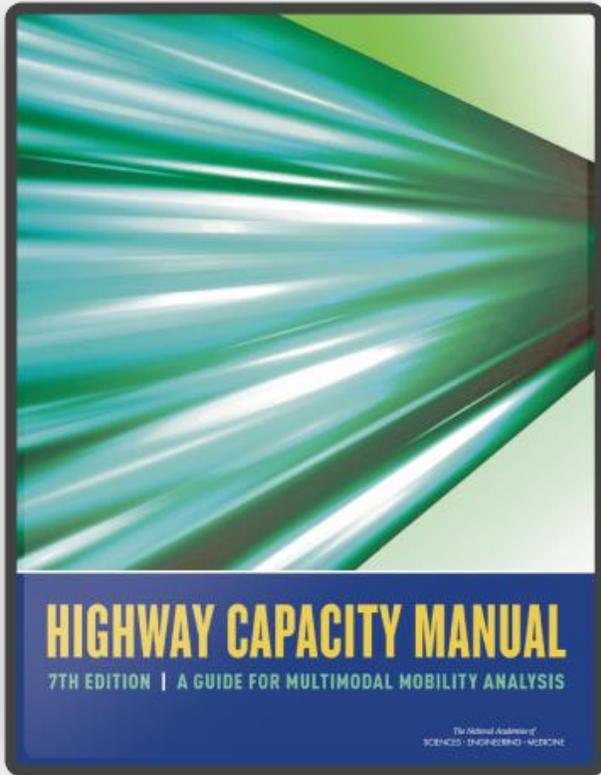
-

**Behzad Aghdashi**

# Capacity Impact for Connected and Automated Vehicles



## Capacity Adjustment for CAVs



### Designed for planning level analyses

State Transportation Improvement Programs (STIP)

### Capacity Adjustment Factors (CAFs) for CAVs

Given a market penetration rate of CAVs, what percent increase in capacity can be expected?

### Connected and Automated Vehicles (CAVs)

- Vehicles communicate with each other and roadside infrastructure
- Cooperative Adaptive Cruise Control (CACC) features enabling platooning operation
- SAE Automation Level 4 or higher

# CAV Capacity Adjustment - Freeways

**Capacity Adjustment Factor ( $CAF_{CAV}$ ) with a multiplicative effect**

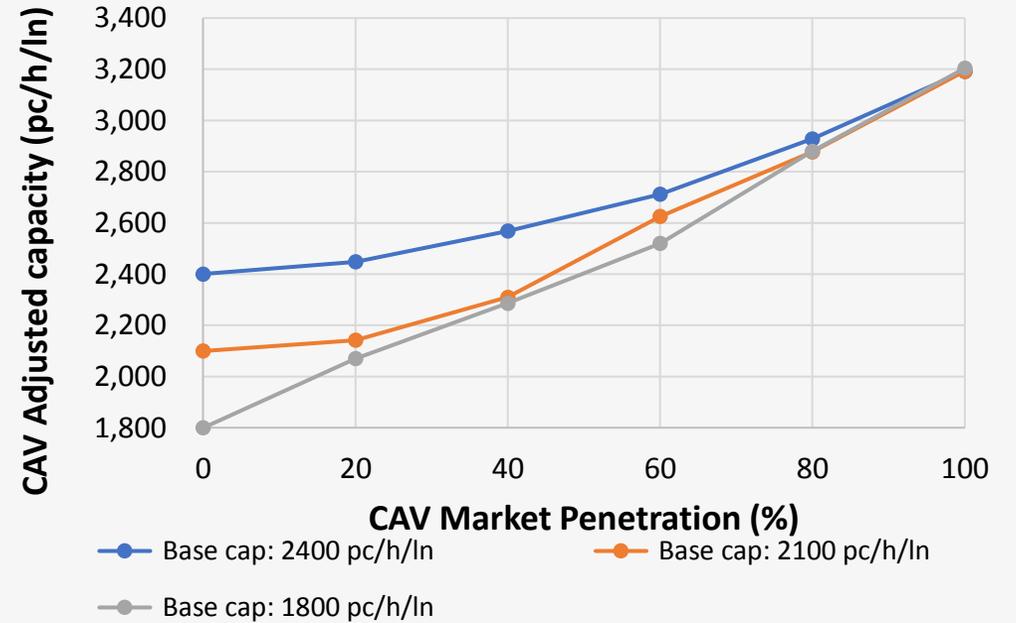
Main user input: **% Market Penetration (0 to 100%)**

- What percentage of the traffic stream is comprised of CAVs?

**Intended for planning-level applications**

**Does not consider:**

- Oversaturated conditions
- CAVs on Managed Lanes
- Truck platooning / connected and autonomous trucks



Proportion of CAVs in Traffic Stream	Adjusted Segment Capacity		
	2,400 pc/h/ln	2,100 pc/h/ln	1,800 pc/h/ln
0	1.00	1.00	1.00
20	1.02	1.02	1.15
40	1.07	1.10	1.27
60	1.13	1.25	1.40
80	1.22	1.37	1.60
100	1.33	1.52	1.78

Capacity adjustments – Basic Segments

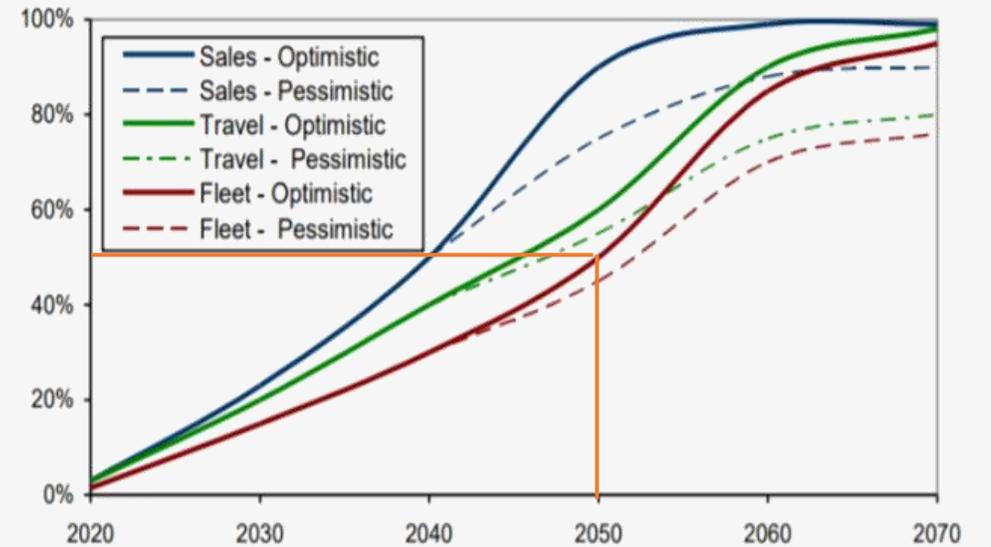
## Case Example - Freeways

What are the expected traffic conditions on California roads by 2050?



Source: CSF2TDM

35% increase in traffic demand



Source: Litman, 2017

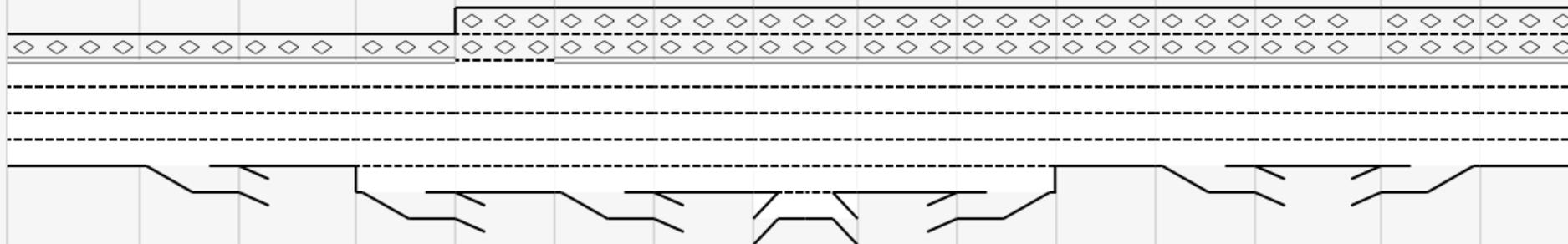
50% CAV market penetration rate

# Case Example

## 2022 BASE CONDITIONS

### I-10 WB @ Los Angeles, CA

GP Type	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Weaving	Basic	Merge	Overlap	Diverge	Basic	Merge	Basic
ML Type	ML Basic	ML Basic	ML Basic	ML Basic	ML Access	ML Basic									
Length, ft	3000	1000	2290	1500	500	1500	250	1720	430	165	1335	165	2700	1500	1000
Segment ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GP Lanes	4	4	4	5	5	5	5	6	5	5	4	4	4	4	4
ML Lanes	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2



### LOS – AM Peak (7 AM – 8:15 PM)

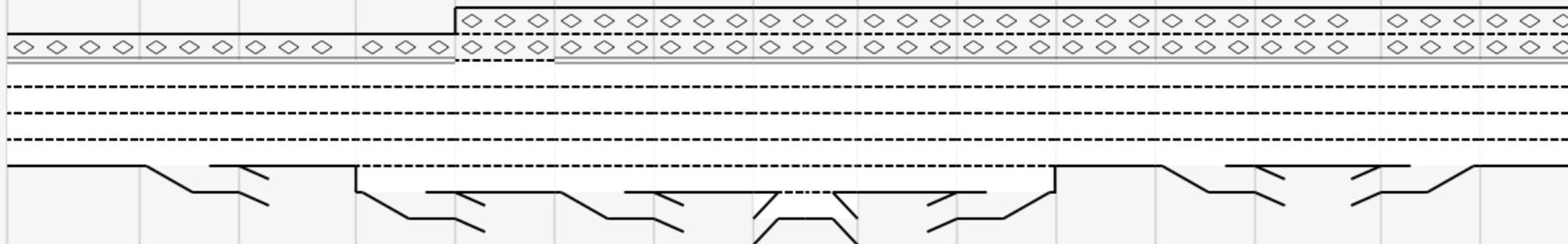
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	D	D	C	C	C	B	B	B	C	C	D	C	C	C	C
7:15 - 7:30	D	C	D	C	C	C	C	C	D	D	D	D	D	C	D
7:30 - 7:45	C	C	C	C	C	C	B	B	C	C	D	D	C	C	D
7:45 - 8:00	C	C	C	C	C	B	B	B	B	C	C	C	B	C	C
8:00 - 8:15	C	C	C	C	C	B	B	B	B	C	C	C	B	C	C

# Case Example

## 2050 – No CAVs

What is the expected LOS in 2050?

GP Type	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Weaving	Basic	Merge	Overlap	Diverge	Basic	Merge	Basic
ML Type	ML Basic	ML Basic	ML Basic	ML Basic	ML Access	ML Basic									
Length, ft	3000	1000	2290	1500	500	1500	250	1720	430	165	1335	165	2700	1500	1000
Segment ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GP Lanes	4	4	4	5	5	5	5	6	5	5	4	4	4	4	4
ML Lanes	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2



LOS – AM Peak (7AM – 8:15 PM) – no CAV considerations

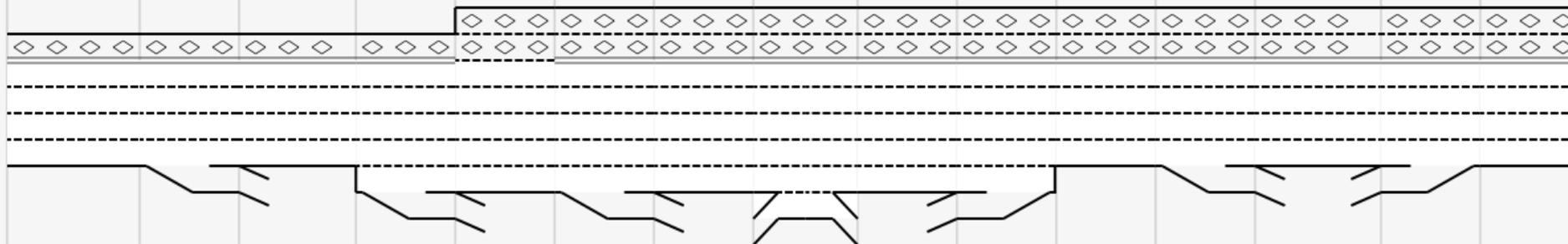
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	E	E	D	E	D	C	C	D	D	D	E	E	D	D	E
7:15 - 7:30	E	E	E	E	F	F	F	F	F	F	F	F	F	F	F
7:30 - 7:45	F	D	D	F	F	F	F	F	F	E	E	E	D	F	E
7:45 - 8:00	D	D	D	E	D	D	C	F	F	D	E	E	D	D	E
8:00 - 8:15	E	D	D	D	D	D	C	D	D	D	E	E	D	D	E

# Case Example

## 2050 – 50% CAVs

What is the expected LOS in 2050?

GP Type	Basic	Diverge	Basic	Diverge	Basic	Diverge	Basic	Weaving	Basic	Merge	Overlap	Diverge	Basic	Merge	Basic
ML Type	ML Basic	ML Basic	ML Basic	ML Basic	ML Access	ML Basic									
Length, ft	3000	1000	2290	1500	500	1500	250	1720	430	165	1335	165	2700	1500	1000
Segment ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
GP Lanes	4	4	4	5	5	5	5	6	5	5	4	4	4	4	4
ML Lanes	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2



LOS – AM Peak (7 AM – 8:15 PM) – 50% CAVs

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	E	E	D	E	D	C	C	D	D	D	E	E	D	D	D
7:15 - 7:30	E	E	E	E	D	D	D	E	E	E	E	E	E	E	E
7:30 - 7:45	D	D	D	E	D	C	C	D	D	E	E	E	D	D	E
7:45 - 8:00	D	D	D	D	C	C	C	C	C	C	D	D	C	D	D
8:00 - 8:15	D	D	D	D	D	C	C	B	C	C	D	D	C	D	D

# Case Example

## Scenario Comparison

2022 Base Conditions

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	D	D	C	C	C	B	B	B	C	C	D	C	C	C	C
7:15 - 7:30	D	C	D	C	C	C	C	C	D	D	D	D	D	C	D
7:30 - 7:45	C	C	C	C	C	C	B	B	C	C	D	D	C	C	D
7:45 - 8:00	C	C	C	C	C	B	B	B	B	C	C	C	B	C	C
8:00 - 8:15	C	C	C	C	C	B	B	B	B	C	C	C	B	C	C

2050 No CAVs

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	E	E	D	E	D	C	C	D	D	D	E	E	D	D	E
7:15 - 7:30	E	E	E	E	F	F	F	F	F	F	F	F	F	F	F
7:30 - 7:45	F	D	D	F	F	F	F	F	F	E	E	E	D	F	E
7:45 - 8:00	D	D	D	E	D	D	C	F	F	D	E	E	D	D	E
8:00 - 8:15	E	D	D	D	D	D	C	D	D	D	E	E	D	D	E

2050 50% CAVs

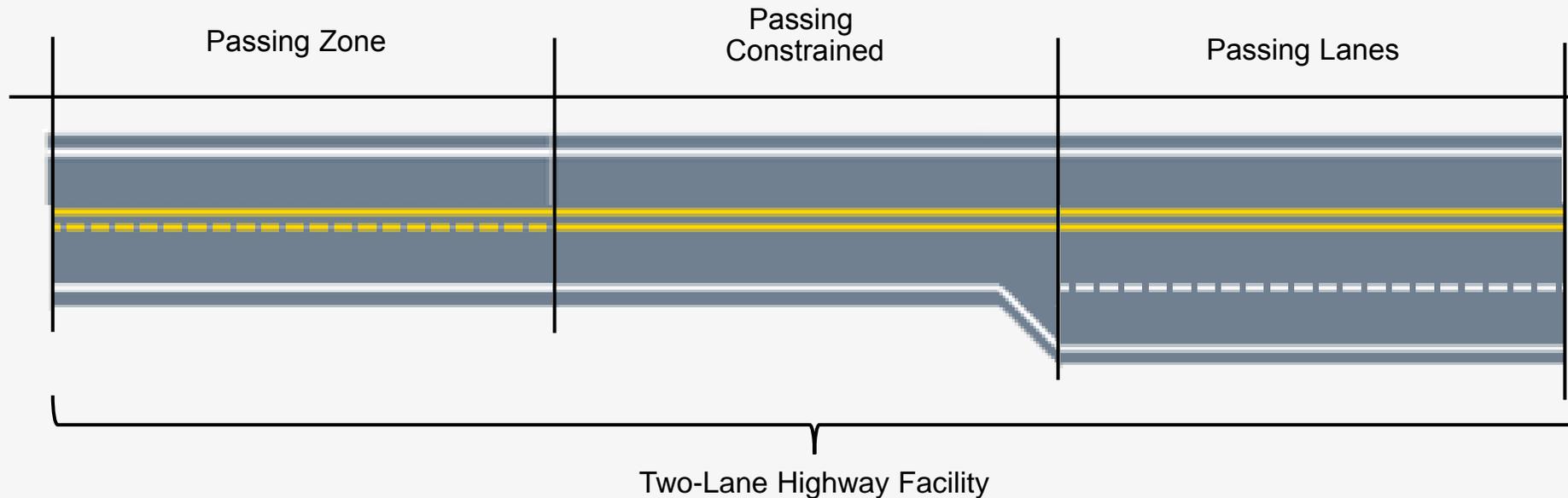
Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
7:00 - 7:15	E	E	D	E	D	C	C	D	D	D	E	E	D	D	D
7:15 - 7:30	E	E	E	E	D	D	D	E	E	E	E	E	E	E	E
7:30 - 7:45	D	D	D	E	D	C	C	D	D	E	E	E	D	D	E
7:45 - 8:00	D	D	D	D	C	C	C	C	C	C	D	D	C	D	D
8:00 - 8:15	D	D	D	D	D	C	C	B	C	C	D	D	C	D	D

# **New Two-Lane Highways Method**



## Revised Chapter 15: Two-Lane Highways

	HCM 6 <sup>th</sup> Edition Methodology	HCM 7 <sup>th</sup> Edition Methodology
<b>Segmentation</b>	<ul style="list-style-type: none"> <li>None - % of passing zones and length of passing lanes are provided</li> </ul>	<ul style="list-style-type: none"> <li>Segment types: Passing zones, passing constrained and passing lanes</li> <li>Subsegments based on horizontal alignment</li> </ul>
<b>Classification</b>	<ul style="list-style-type: none"> <li>Class I, Class II, Class III</li> </ul>	<ul style="list-style-type: none"> <li>N/A</li> </ul>



# Revised Chapter 15: Two-Lane Highways

	HCM 6 <sup>th</sup> Edition Methodology	HCM 7 <sup>th</sup> Edition Methodology
<b>Performance Measures</b>	<ul style="list-style-type: none"> <li>Average Travel Speed</li> <li>Percent Time Spent Following</li> <li>Percent of Free-Flow Speed</li> </ul>	<ul style="list-style-type: none"> <li>Average Speed</li> <li>Percent Followers</li> <li><b>Follower Density (Service Measure)</b></li> </ul>
<b>Heavy vehicles</b>	<ul style="list-style-type: none"> <li>Passenger Car Equivalent (pc/h)</li> <li>Presence of RVs</li> </ul>	<ul style="list-style-type: none"> <li>Flow as veh/h</li> <li>% HV as a direct input for performance measures</li> </ul>
<b>Capacity</b>	<ul style="list-style-type: none"> <li>1,700 pc/h</li> </ul>	<ul style="list-style-type: none"> <li>1,700 veh/h for passing zones and passing constrained</li> <li>Variable for passing lanes</li> </ul>

LOS	Class I Highways		Class II Highways	Class III Highways
	ATS (mi/h)	PTSF (%)	PTSF (%)	PFFS (%)
A	>55	≤35	≤40	>91.7
B	>50–55	>35–50	>40–55	>83.3–91.7
C	>45–50	>50–65	>55–70	>75.0–83.3
D	>40–45	>65–80	>70–85	>66.7–75.0
E	≤40	>80	>85	≤66.7
F	Demand exceeds capacity			

Note: For Class I highways, LOS is determined by the worse of ATS-based LOS and PTSF-based LOS.

HCM 6<sup>th</sup> Edition – LOS criteria

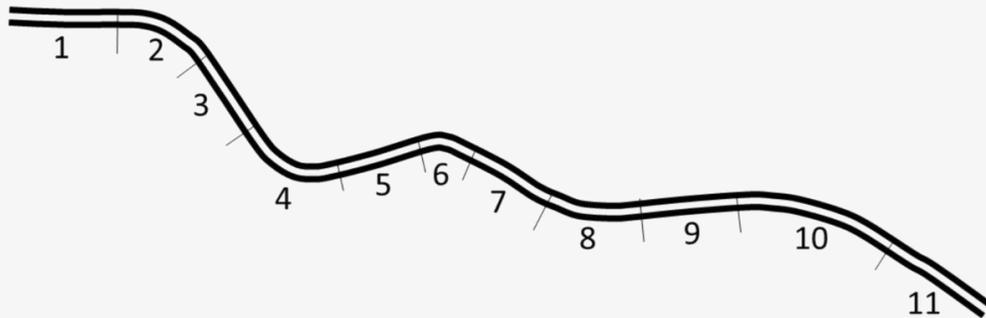
LOS	Follower Density (followers/mi/ln)	
	Higher-Speed Highways Posted Speed Limit ≥ 50 mi/h	Lower-Speed Highways Posted Speed Limit < 50 mi/h
A	≤ 2.0	≤ 2.5
B	> 2.0 – 4.0	> 2.5 – 5.0
C	> 4.0 – 8.0	> 5.0 – 10.0
D	> 8.0 – 12.0	> 10.0 – 15.0
E	> 12.0	> 15.0
F	Demand exceeds capacity	

HCM 7<sup>th</sup> Edition – LOS criteria

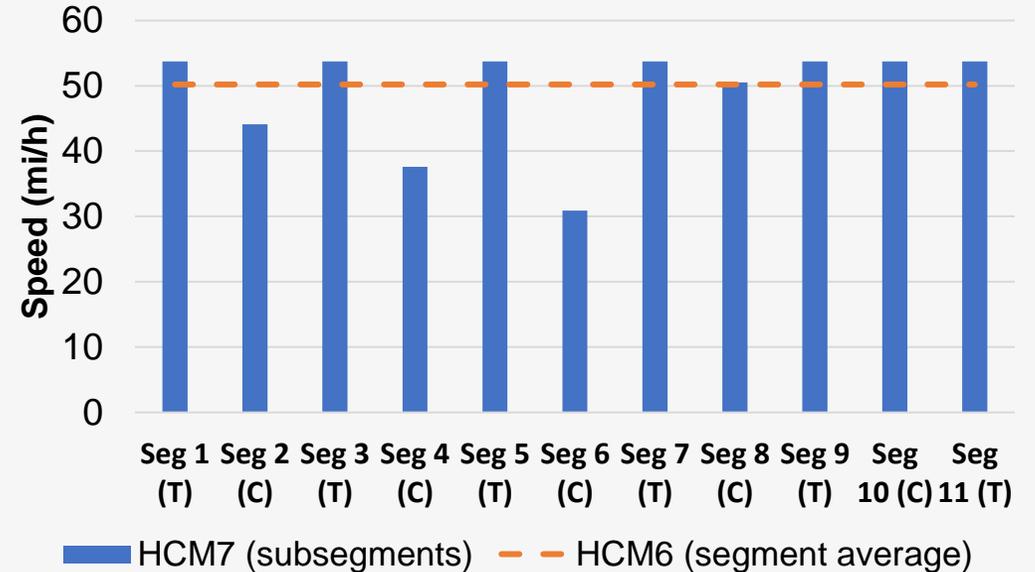
# Sensitivity to Horizontal Curvature

## Estimated speeds – new method x old method

Speeds can change significantly in curve segments



Subsegment	Type	Length (ft) <sup>a</sup>	Super-elevation (%)	Radius (ft)	Central Angle (deg)	Horizontal Class <sup>b</sup>
1	Tangent	280	--	--	--	--
2	Horizontal curve	432	3	450	55	3
3	Tangent	260	--	--	--	--
4	Horizontal curve	366.5	2	300	70	4
5	Tangent	250	--	--	--	--
6	Horizontal curve	216	5	275	45	5
7	Tangent	275.6	--	--	--	--
8	Horizontal curve	458	0	750	35	2
9	Tangent	285	--	--	--	--
10	Horizontal curve	767.9	4	1,100	40	1
11	Tangent	369	--	--	--	--
<b>Total</b>		<b>3,960</b>				



## Case Example – Two-Lane Highways

### Evaluate LOS of a Two-Lane Highway Facility – Eastbound Direction

Juniper Springs is a popular spring serviced by FL-40, a scenic two-lane highway in Ocala/FL



*PZ: Passing zone;*

*PC: Passing constrained;*

*PL: Passing lane;*

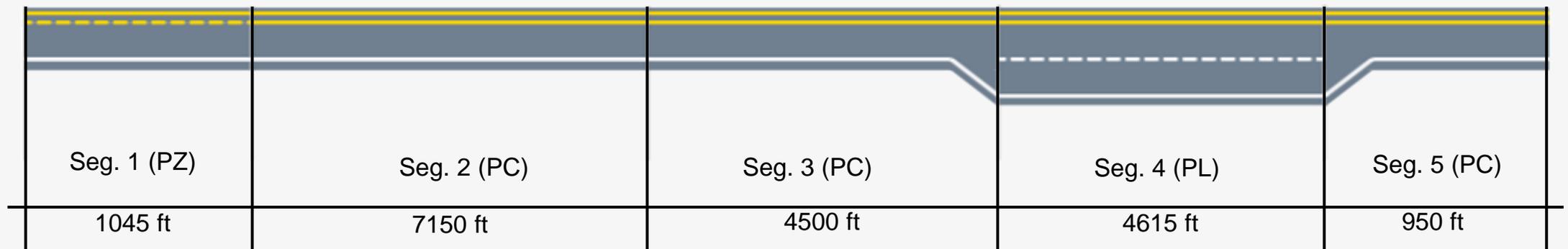
## Case Example – Two-Lane Highways

### Input Data

Highway schematic (Eastbound direction):

- Posted speed limit = 55 mi/h
- Level terrain (0% grade)
- 8% heavy vehicles
- PHF: 0.95

Segment #	Directional Volume (veh/h)	Opposing Volume (veh/h)
1	470	380
2	470	-
3	500	-
4	500	-
5	500	-



*PZ: Passing zone;*

*PC: Passing constrained;*

*PL: Passing lane;*

# Case Example – Two-Lane Highways

## Input Data

### Additional geometric data:

- Shoulder width: 6 ft
- Access Point Density: 0
- Lane width: 12 ft

Segment #	Type	Length (ft)	Curve radius (ft)	Superelevation (%)
1	Tangent	1045	-	-
2	Tangent	7150	-	-
3	Tangent	650	-	-
3	Horizontal Curve	1990	5730	3
3	Tangent	1860	-	-
4	Tangent	700	-	-
4	Horizontal Curve	1480	2860	5
4	Tangent	2435	-	-
5	Tangent	950	-	-

**Segment**

None

Speed

Follower Density

LOS

BLOS Score

Type	Length, ft	Segment ID	PZ	PC	PC	PL	PC
	1845	1		7150	4500	4615	950
		2					
		3					
		4					
		5					



**Geometric Data**

Coded Type: Passing Constrained

Measured FFS:

Free Flow Speed, mi/h:

Lane Width, ft:

Grade, %:

Pavement Condition Rating:

Length Used in Calculation, mi: 0.85

Analyze Bicycle Results:

Speed Limit, mi/h:

Shoulder Width (Paved), ft:

Access Point Density, points/mi:

Percent Occupied Parking, %:

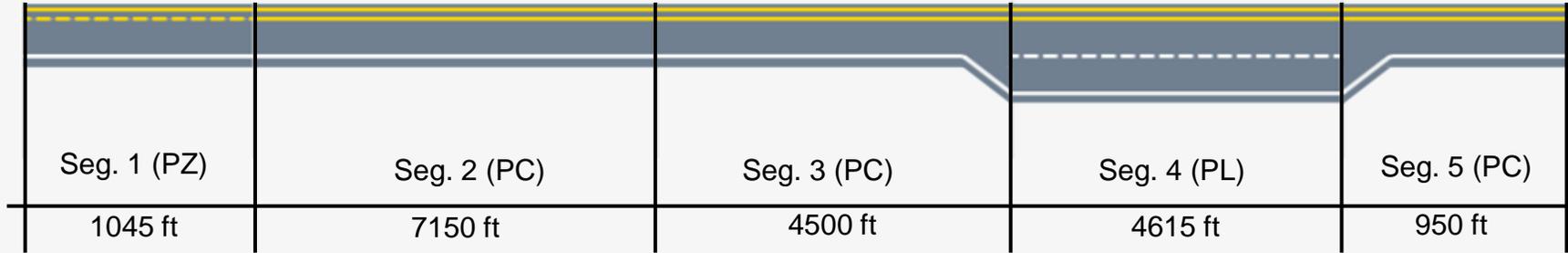
**Subsegments**

Add Subsegment
Insert Subsegment
Delete Subsegment

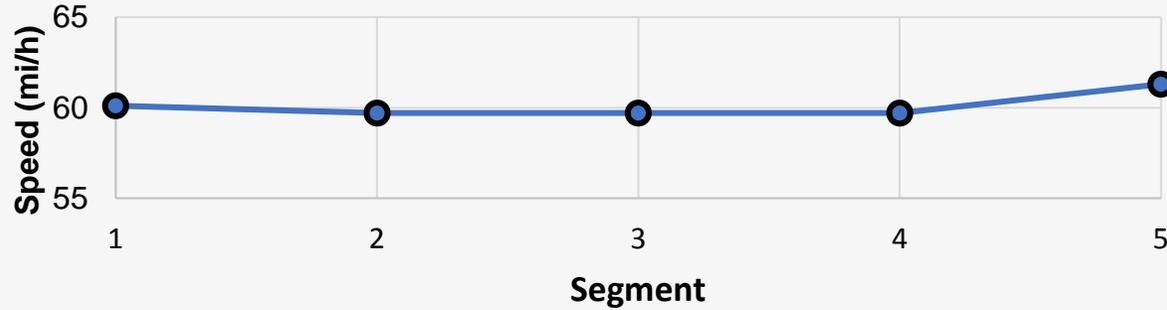
Type	Length, ft	Radius ft	Superelevation, %
1 Tangent	650	-	-
2 Horizontal Curve	1990	5730	3.0
3 Tangent	1860	-	-

# Case Example – Two-Lane Highways

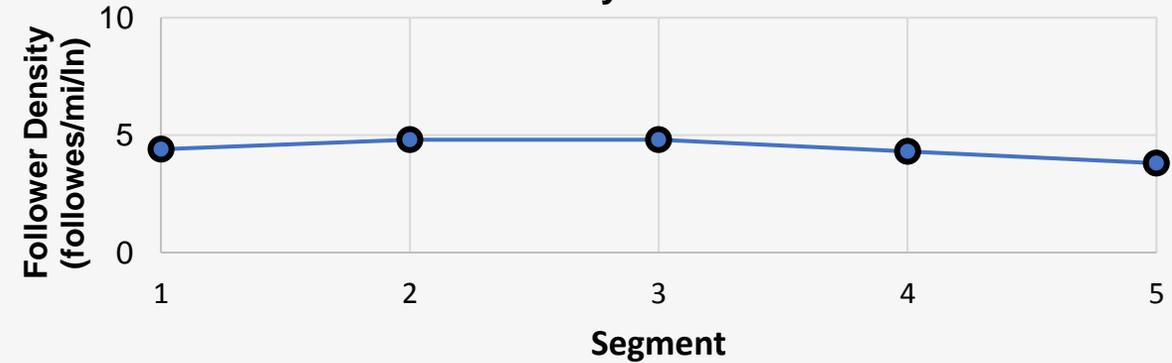
## Results



Speed Distribution



Follower Density Distribution

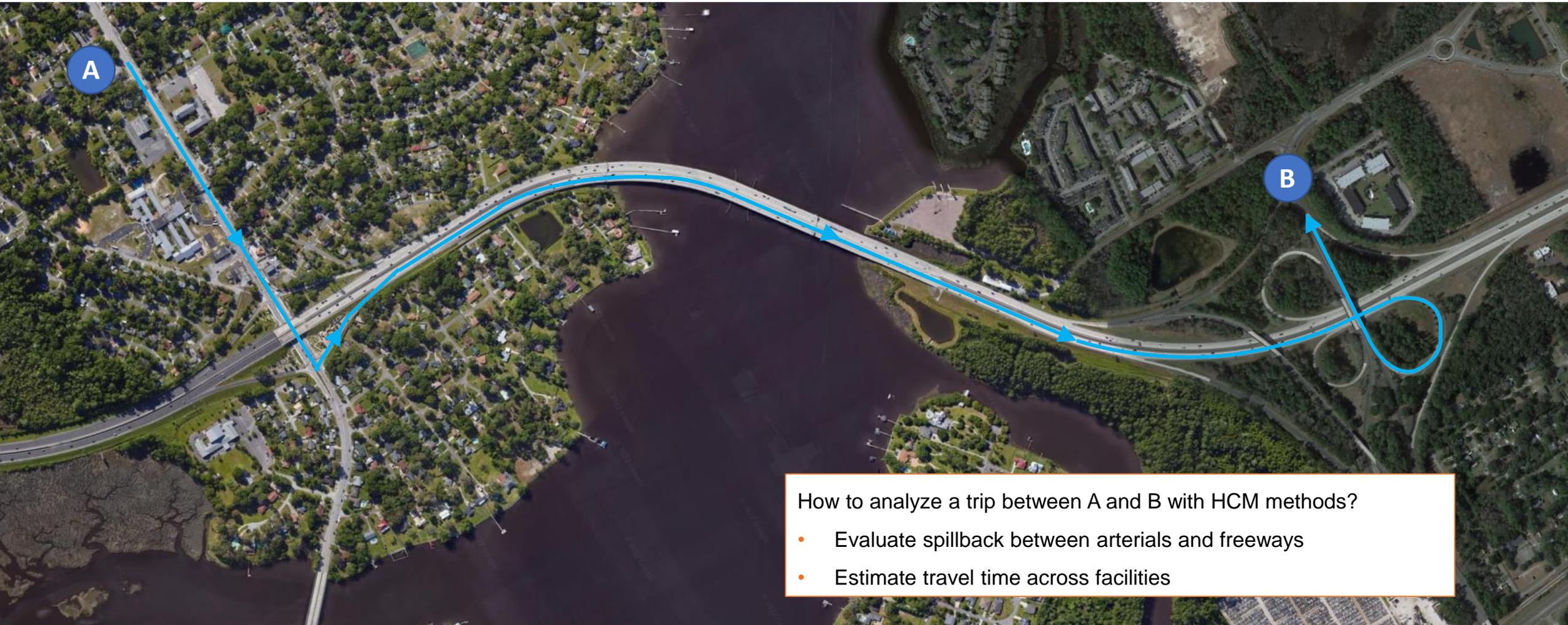


Facility Results				
T	VMT veh-mi/p	VHD veh-h/p	Follower Density, followers/ mi/ln	LOS
1	431	0.31	3.9	B

## **New Network Method**



## NCHRP 15-57: New HCM Chapter 38 on Network Analysis

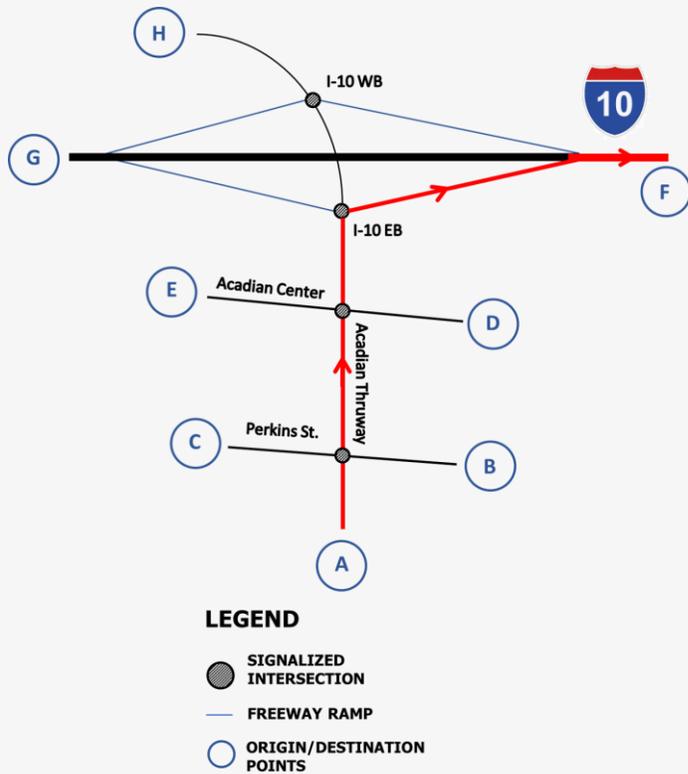


How to analyze a trip between A and B with HCM methods?

- Evaluate spillback between arterials and freeways
- Estimate travel time across facilities

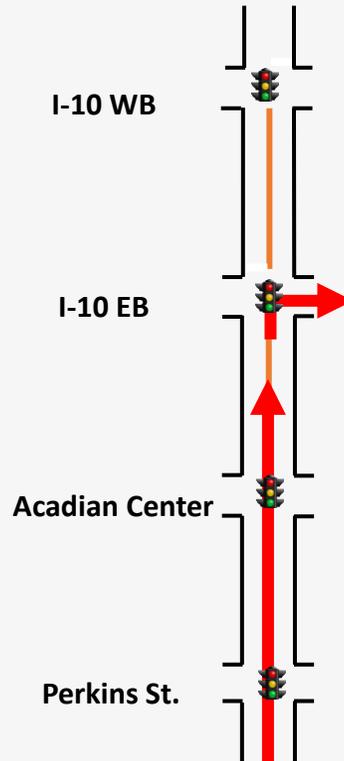
# Analyzing Corridors with Freeways and Streets

How to analyze a trip from A to F?

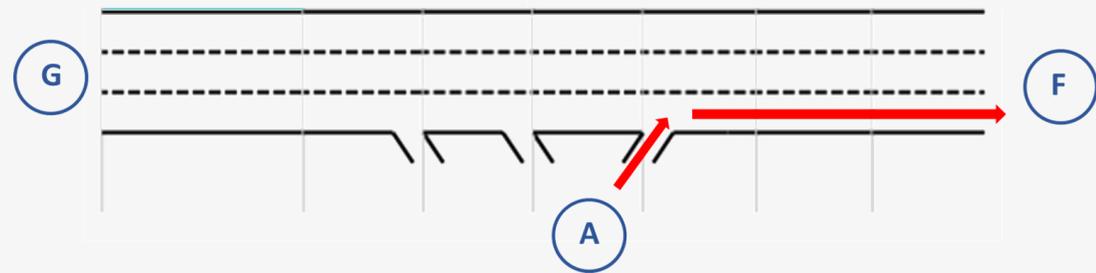


HCM Current methods – analyze two different facilities:

Facility 1 (Urban Street):



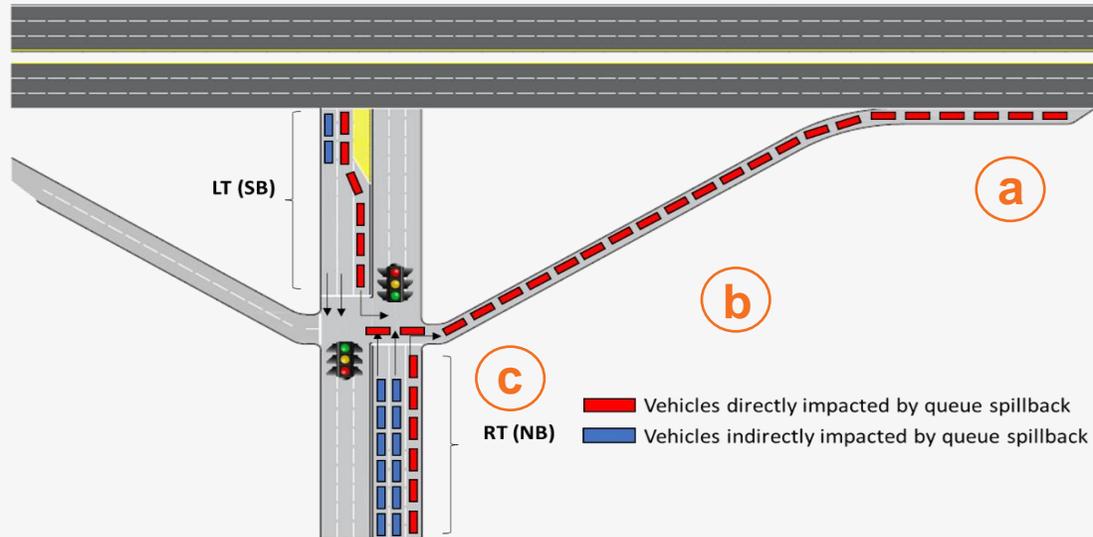
Facility 2 (Freeway):



HCM New methods – integrates analyses and overcomes limitations:

- Travel time as common performance measure
- Congestion propagation at interchanges (queue spillback)
- Lane selection at freeway depending on O-D
- Travel time at freeway ramps

# Analyzing Corridors with Freeways and Streets



## On-Ramp Queue Spillback

Occurs when:

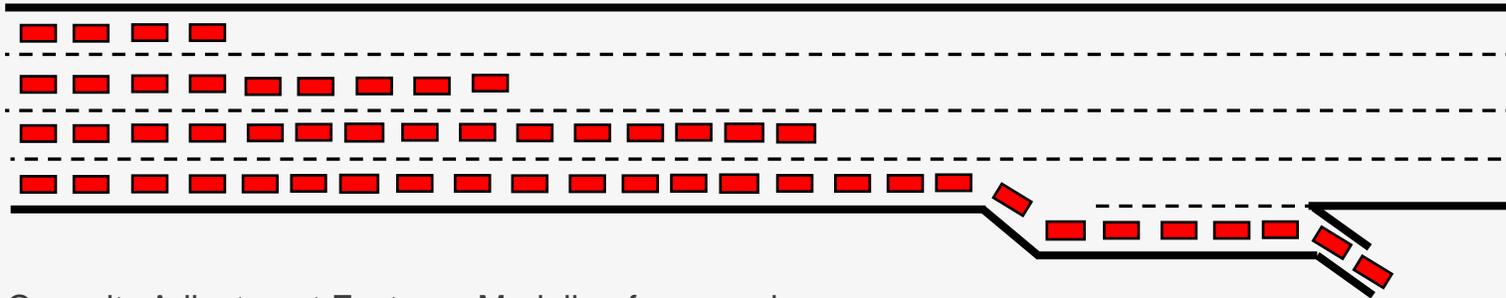
- Insufficient capacity at:
  - a) freeway merge
  - b) ramp meter or
  - c) ramp roadway
- Insufficient storage length at the on-ramp

## User Inputs

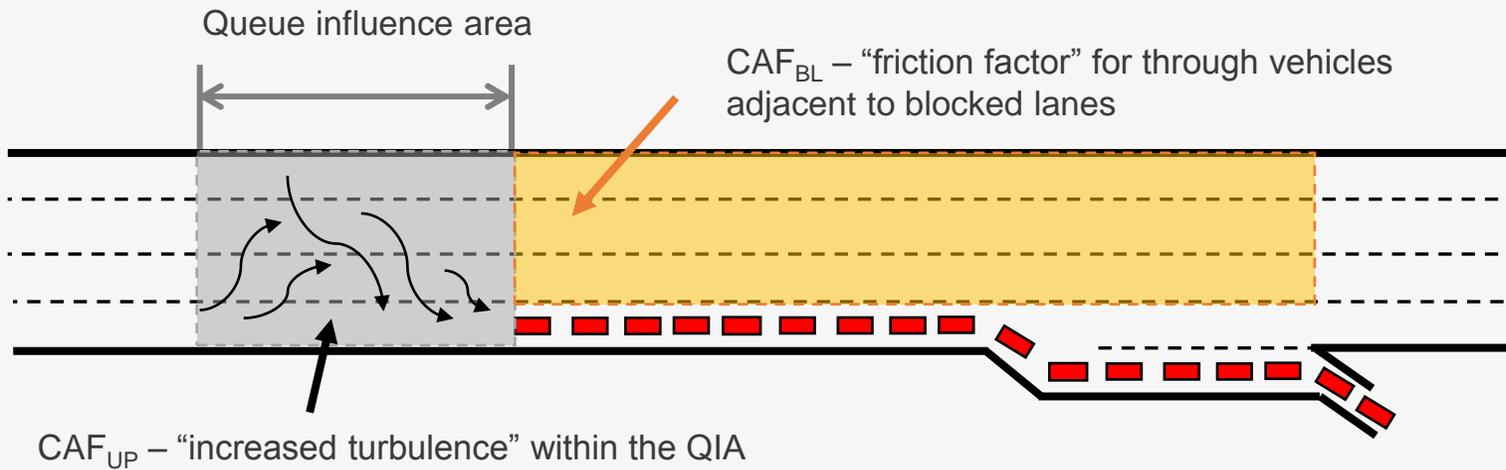
- Available queue storage at the on-ramp (ft)
- Ramp metering rate, if applicable (veh/h)
- Intersection and Freeway inputs per existing HCM methods

# Queue Spillback Analysis – Freeway Off-ramps

Freeway impact is more localized close to exit and spreads further upstream:



Capacity Adjustment Factors - Modeling framework:



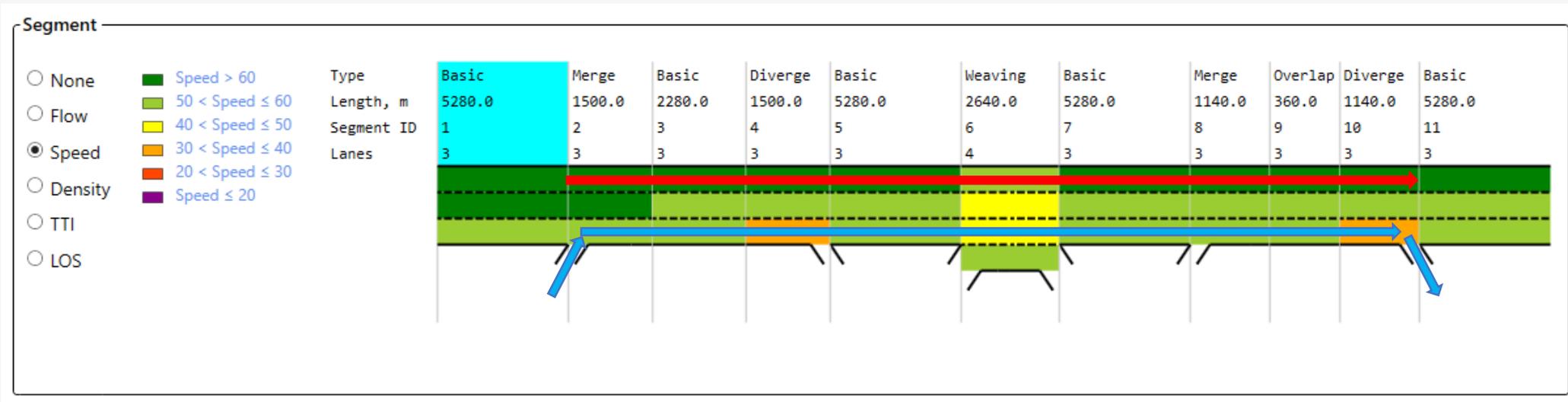
# Freeway Lane-by-Lane Performance

Instrumental to analyze O-D based travel times – affects lane choice

Estimation of capacity and speeds for individual lanes

Flow distribution for individual lanes as function of:

- Segment and ramp flow rate; % grade; nearby ramps; number of lanes

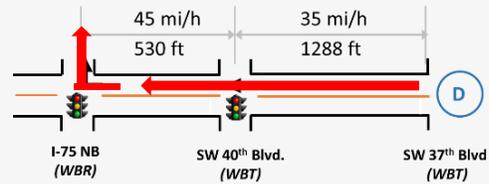


*How do travel times between these two O-D pairs differ?*

# Numerical Example

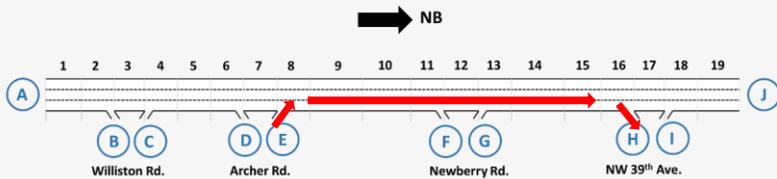
## HCM 6<sup>th</sup> Edition - Current methods

Facility 1 (Urban Street):



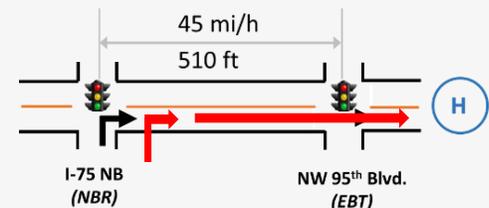
LOS=F  
TT=478 s

Facility 2 (Freeway):



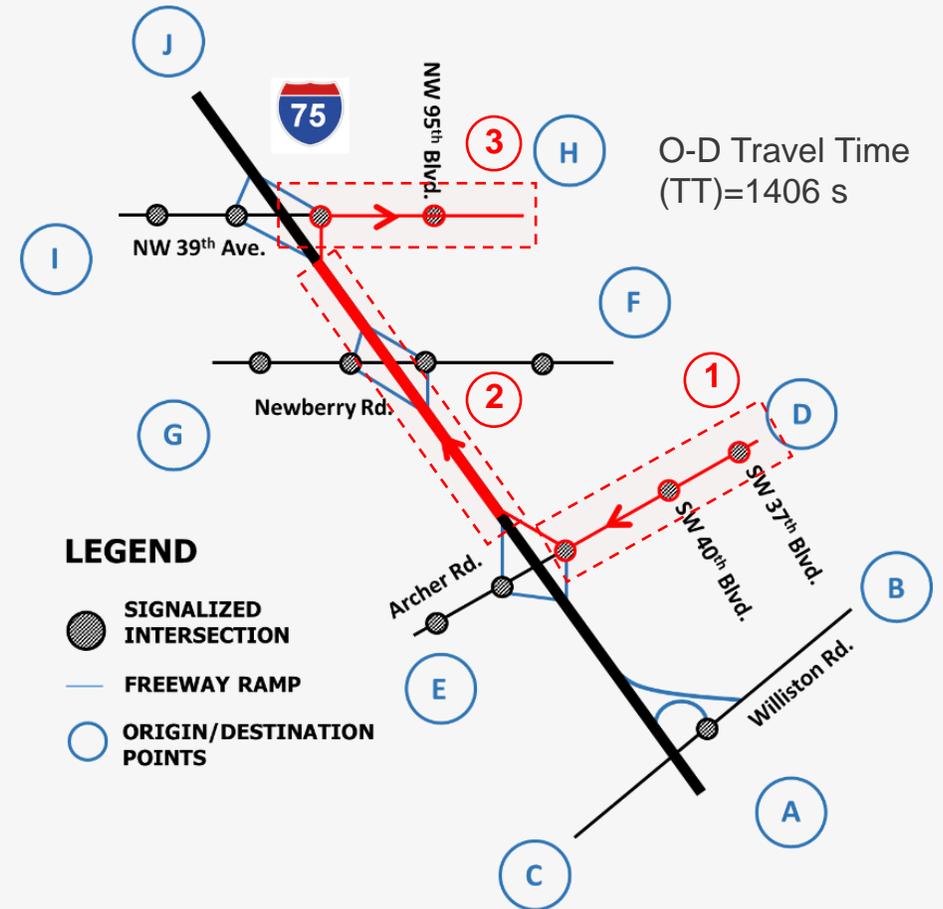
LOS=D  
TT=735 s

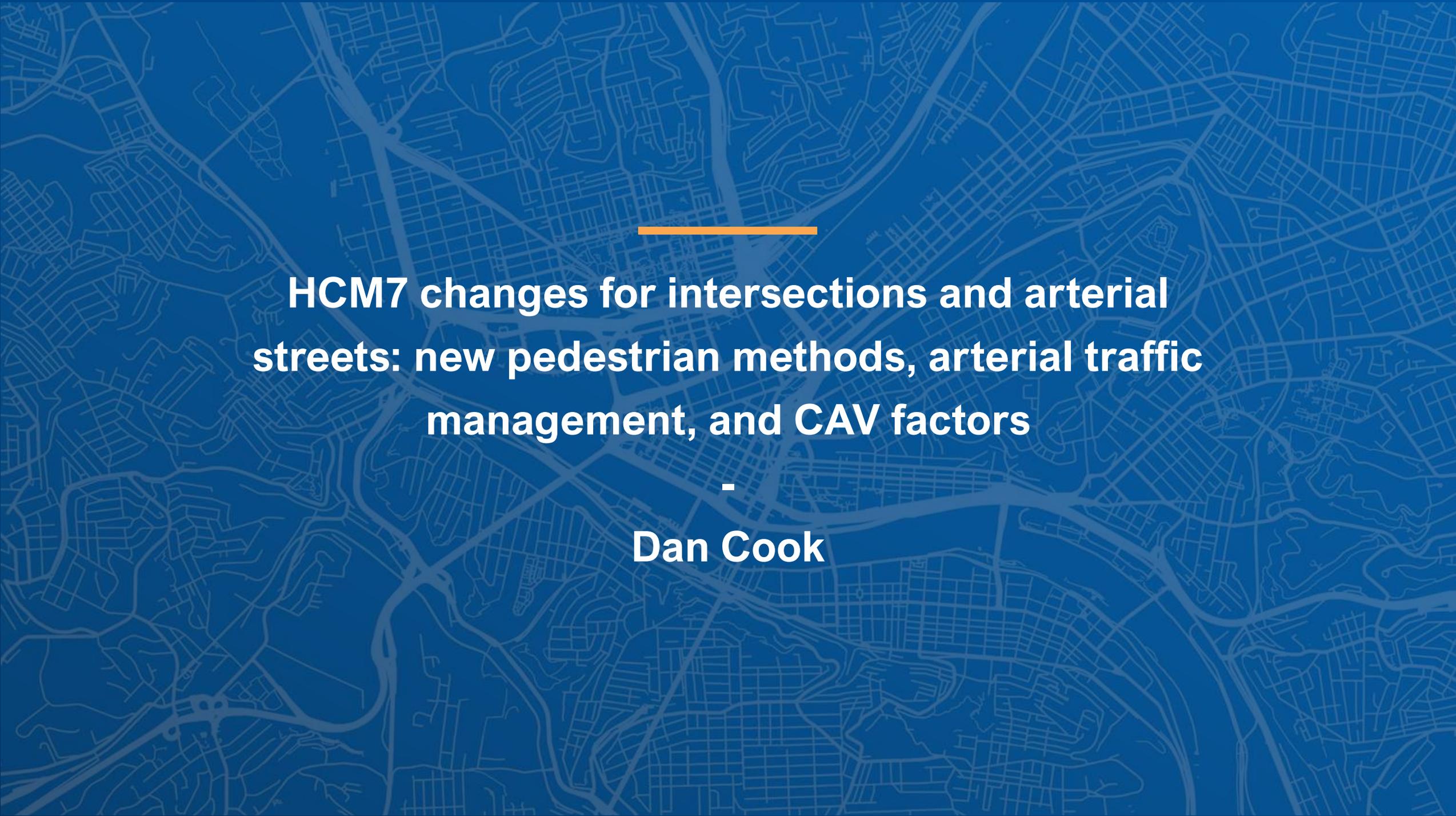
Facility 3 (Urban Street):



LOS=E  
TT=193 Sec

## HCM 7<sup>th</sup> Edition - New methods





---

**HCM7 changes for intersections and arterial streets: new pedestrian methods, arterial traffic management, and CAV factors**

-  
**Dan Cook**

An aerial photograph of a busy pedestrian crossing, overlaid with a semi-transparent blue filter. The crossing is marked with white zebra stripes. Numerous pedestrians are seen walking across the street. A white car is partially visible on the left side, and a dark van is at the bottom left. A red trash bin is at the bottom center. A thin orange horizontal line is positioned above the title text.

## Enhanced Pedestrian Volume Estimation and Evaluation Method

# What's New: Uncontrolled Crossings (TWSC & Midblock)

## HCM6 Method

- LOS based on pedestrian delay
- LOS sensitive to:
  - Hourly traffic flow rate
  - Motorist yielding rate

## HCM7: New method

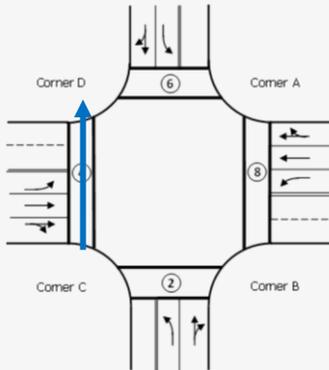
- LOS based on percentage (dis)satisfied pedestrians
- LOS sensitive to:
  - Hourly traffic flow rate
  - AADT
  - Motorist yielding rate
  - Specific crossing treatments (marked crosswalk, median island, RRFB)
- Delay is still calculated and is sensitive to the design pedestrian (assumed pedestrian speed)
- Corrections to the HCM6 motorist yielding procedure



# What's New: Signalized Crossing Delay

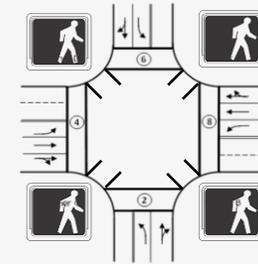
## HCM6 Method

- Delay estimated for single-leg, single-stage crossings
- Guidance to sum delay results for multiple-leg crossings
- LOS based on “pedestrian LOS score” (uses multiple factors relating to crossing experience)
- Corner and crosswalk circulation area calculated before delay & LOS

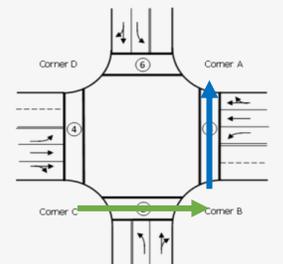


## HCM7: New methods

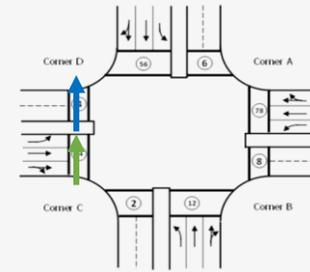
- Delay also estimated for multiple-leg and multiple-stage crossings
- Delay calculation recognizes that second stage/leg arrival is not random
- LOS continues to be based on pedestrian LOS score
- Corner and crosswalk circulation area become optional calculation steps



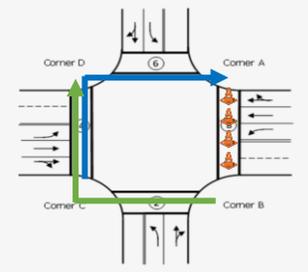
Barnes dance / pedestrian scramble



Two-leg crossing



Two-stage crossing with median refuge

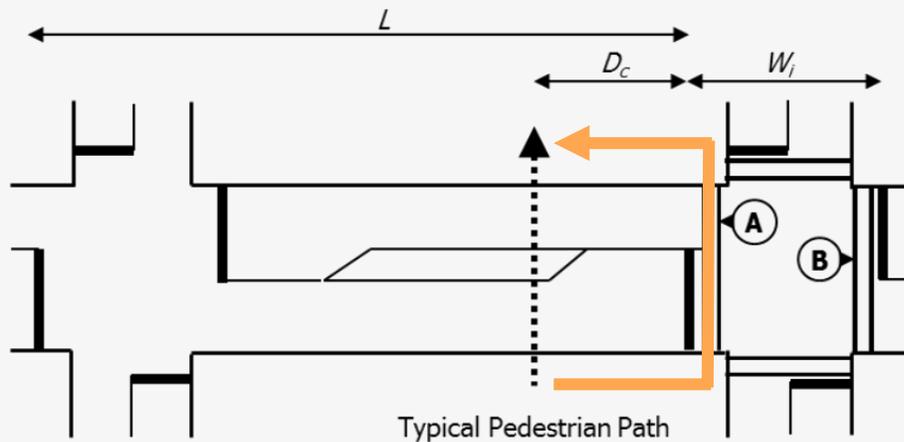


Crosswalk closure (three-leg crossing)

# Urban Street Pedestrian LOS Method

## HCM6 Method

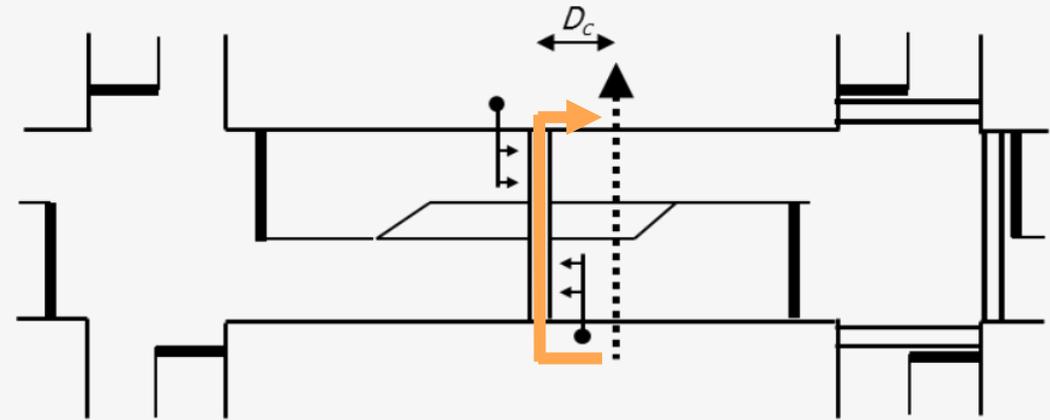
- Segment pedestrian LOS influenced by ease of crossing the street between signalized intersections
- Method has little sensitivity to diversion length



(a) Divert to Nearest Boundary Intersection

## HCM7: Revised method

- Increased sensitivity to diversion length



(b) Divert to Midsegment Signalized Crosswalk



## Capacity Impact for Connected and Automated Vehicles

# CAV Capacity Adjustment: Signalized Intersections

## Adjustment to Saturation Flow Rate

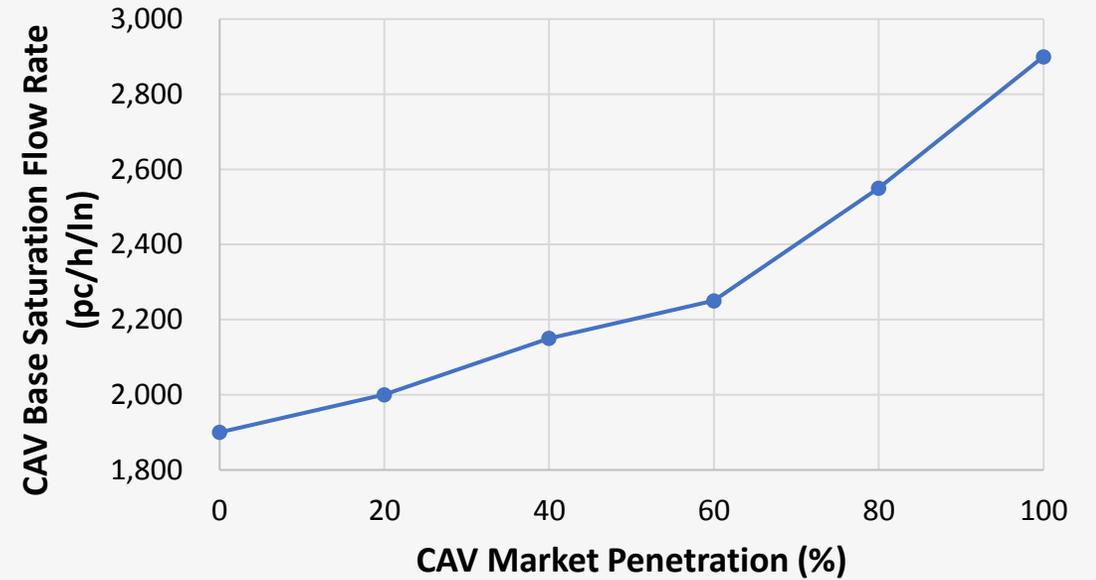
Main user input: **% Market Penetration (0 to 100%)**

- What percentage of the traffic stream is comprised of CAVs?

## Addresses protected and permitted phases

### Does not consider:

- Interactions with pedestrians and other modes
- Driveways or access points impacting saturation flow rates



Proportion of CAVs in Traffic Stream	Base Saturation Flow Rate (pc/h/ln)
0	1,900
20	2,000
40	2,150
60	2,250
80	2,550
100	2,900

*Saturation Flow Rate adjustments – Through movements*

# CAV Service Volume Tables - Signals

**Exhibit 31-67**  
Illustrative Generalized  
Service Volumes LOS=E  
Thresholds for Signalized  
Intersections with CAV  
presence (veh/h)

Through Movement g/C Ratio	No of Through Lanes	Proportion of CACC-Capable Vehicles in Traffic Stream					
		0	20	40	60	80	100
0.40	1	800	840	910	950	1,070	1,220
	2	1,550	1,630	1,750	1,840	2,080	2,370
	3	2,000	2,110	2,260	2,370	2,680	3,050
0.45	1	910	960	1,030	1,080	1,220	1,390
	2	1,740	1,830	1,970	2,060	2,340	2,660
	3	2,250	2,370	2,550	2,660	3,020	3,430
0.50	1	1,020	1,070	1,150	1,210	1,370	1,560
	2	1,930	2,030	2,180	2,290	2,590	2,950
	3	2,500	2,630	2,830	2,960	3,360	3,820

Notes: LOS E threshold is defined by control delay greater than 80 s/veh or volume-to-capacity ratio >1.0.

CAV = connected and autonomous vehicle, CACC = cooperative adaptive cruise control.

Assumes no interaction with non-motorized road users, no adverse weather impacts, and a facility without driveways or access points impacting saturation flow rates.

Interpolate for other CACC proportions

Assumed values for all entries:

Heavy vehicles: 0%

Peak hour factor: 0.92

Lane width: 12 ft

Grade: 0%

Separate left-turn lane: yes

Separate right-turn lane: no

Pretimed control

Cycle length: 90 s

Lost time: 4 s/phase

Protected left-turn phasing: yes

g/C ratio for left-turn movement: 0.10

Parking maneuvers per hour: 0

Buses stopping per hour: 0

Percentage left turns: 10%

Percentage right turns: 10%

1  
2  
3  
4  
5  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21

# CAV Capacity Adjustment - Roundabouts

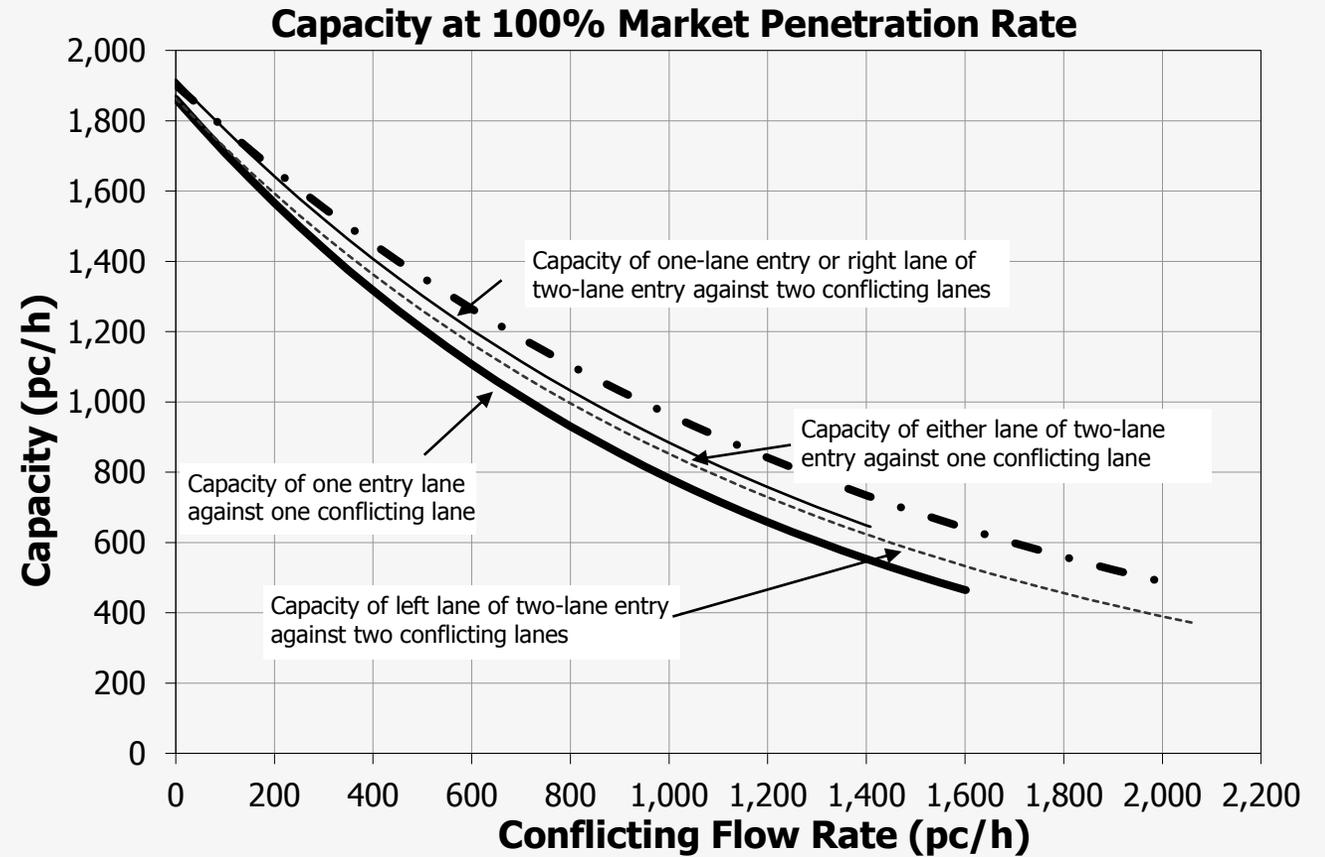
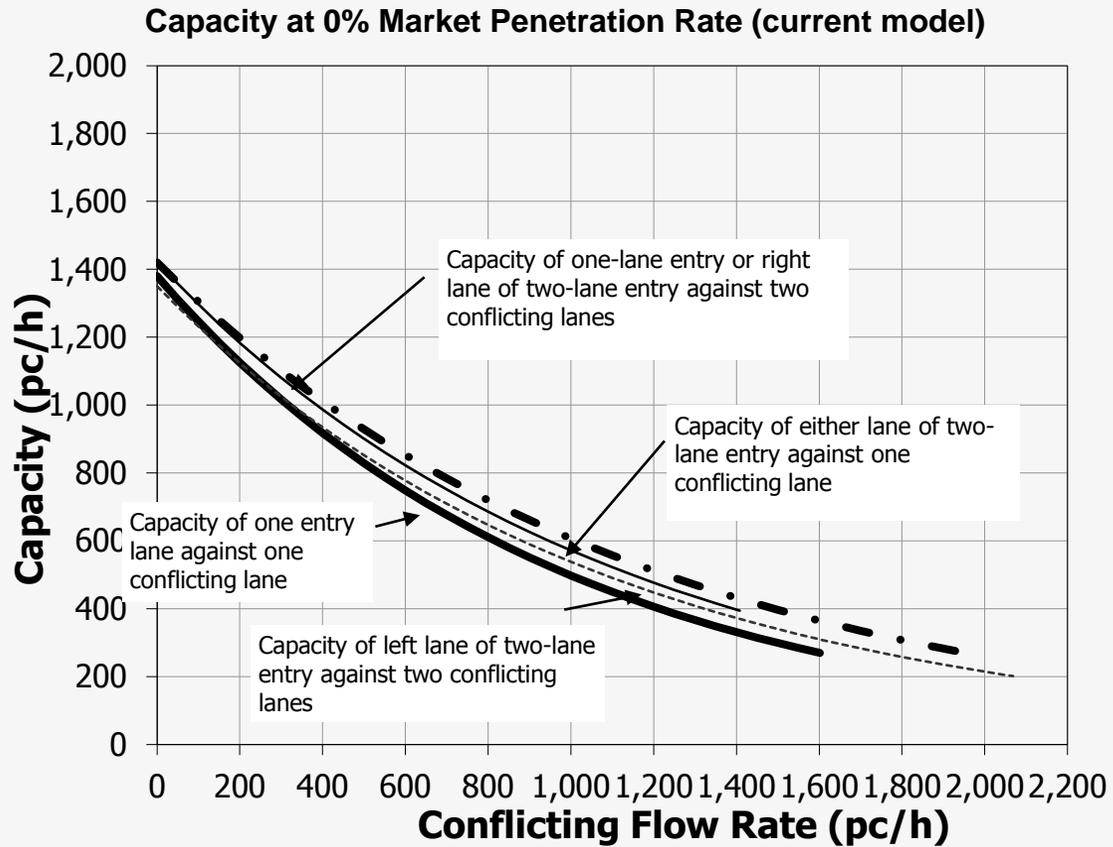
## Adjustment to Follow-up Headway and Critical-Headway

Main user input: % Market Penetration (0 to 100%)

- What percentage of the traffic stream is comprised of CAVs?

Proportion of CAVs in Traffic Stream	<u>1-Lane Entry</u>				<u>2-Lane Entry</u>					
	<u>1 Circulating Lane</u>		<u>2 Circulating Lanes<sup>a</sup></u>		<u>1 Circulating Lane, Both Lanes<sup>a</sup></u>		<u>2 Circulating Lanes, Left Lane</u>		<u>2 Circulating Lanes, Right Lane</u>	
	$f_A$	$f_B$	$f_A$	$f_B$	$f_A$	$f_B$	$f_A$	$f_B$	$f_A$	$f_B$
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	1.05	0.99	1.03	0.99	1.05	0.99	1.03	0.99	1.05	0.96
40	1.12	0.97	1.08	0.96	1.12	0.97	1.08	0.96	1.12	0.93
60	1.22	0.94	1.18	0.92	1.22	0.94	1.18	0.92	1.20	0.87
80	1.29	0.90	1.28	0.89	1.29	0.90	1.28	0.89	1.27	0.84
100	1.35	0.85	1.38	0.85	1.35	0.85	1.38	0.85	1.34	0.80

# CAV Capacity Adjustment – Roundabout Capacity Curves





---

# HCM Multimodal Methods

-  
**Ana Moreno**

# Pedestrian & Bicyclist QOS Application Examples

## Evaluating pedestrian, bicyclist satisfaction with a specific facility element

- Crossing a street
- Walking/biking along a street
- Using an off-street path

## Evaluating user satisfaction changes when street space is reallocated among modes

- Motor vehicle drivers & passengers
- Pedestrians
- Bicyclists
- Transit passengers



Kittelson &amp; Associates / Caitlin Tobin



Kittelson &amp; Associates / Dorrett Oosterhoff

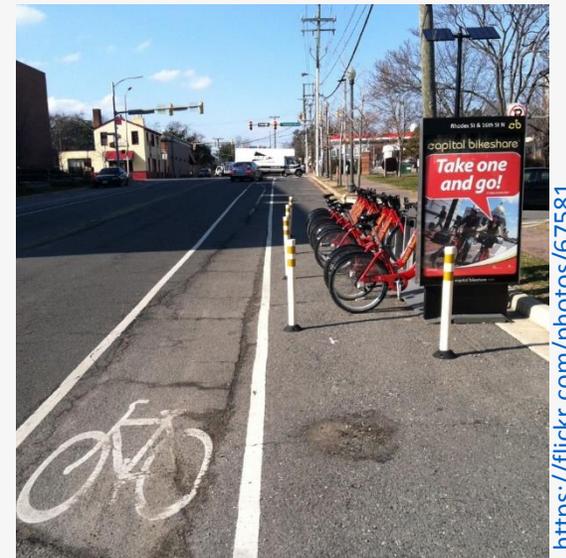
# Bicycle Analysis Methods in the HCM

## HCM6 and HCM7 methods

- Many bicycle methods (and metrics) are in HCM
    - Urban street segments
    - Signalized intersections
    - Urban street facilities
    - Two-lane highways
    - Multilane highways
    - Off-street paths
      - Exclusive bicycle facilities
      - Shared-use paths
- } Applies to shared or exclusive lanes
- } Applies to paved shoulders, bicycle lanes, and shared lanes
- LOS based on Bicycle LOS score (BLOS) that predict how modal users would rate their experience (1 = best, 6 = worst)
  - BLOS were developed from surveys of user satisfaction



<https://felixwong.com/2009/10/noodles-2-noodles-100/>



<https://flickr.com/photos/67581892@N05/8474404173>

# Types of Bicycle Performance Measures

## Quality of Service

- Measures of how well bicycle facilities operate from a cyclist's perspective
- Incorporates multiple factors that a roadway agency can influence
  - Examples: bicycle lane width, traffic volume/speed, pavement quality
- Included in all editions since 2010 HCM

## Level of Traffic Stress

- Establish a particular level of service as the minimum required to serve the mainstream population, segmented in four design user profiles
  - Children, interested but concerned, somewhat confident, highly confident
- Speed limit, street width, presence of parking lanes, bike lane blockage, etc.
- Not addressed by the HCM



Kittelison &amp; Associates / Lee Rodegerdtis



Kittelison &amp; Associates / Paul Ryus

# Bicycle Operations Application Examples

- Designing bicycle facility width to accommodate a given number of bicyclists
- Evaluating and comparing bicyclist delay at traffic signals
- Evaluating how frequently bicyclists will be impeded by other multi-use path users



Kittelson &amp; Associates / Paul Ryus

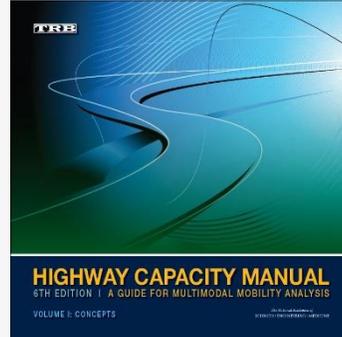


Kittelson &amp; Associates / Lee Rodegerdt

# Pedestrian Analysis Methods in the HCM

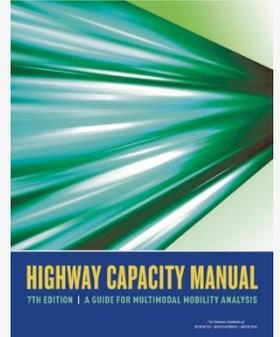
## HCM6 methods

- Uncontrolled crossings
  - Pedestrian delay
- Signalized crossings
  - Pedestrian delay (one leg, one stage)
  - Pedestrian quality of service (QOS)
- Urban streets
  - Pedestrian density
  - Pedestrian QOS
- Off-street paths
  - Pedestrian density



## New and *updated* methods in HCM7

- Uncontrolled crossings
  - *Pedestrian delay* (driver yielding)
  - **Pedestrian satisfaction**
- Signalized crossings
  - **Pedestrian delay** (multiple legs, multiple stages, signal phasing options)
- Urban streets
  - *Pedestrian QOS* (street-crossing difficulty)



# Types of Pedestrian Performance Measures

## Operations

- Pedestrian counterparts to motor vehicle measures
- Delay, density, space, capacity
- Included in all editions since 1985 HCM

## Quality of Service

- Measures of how well pedestrian facilities operate from a pedestrian's perspective
- Incorporates multiple factors that a roadway agency can influence
  - Examples: sidewalk width, separation from traffic, traffic volume/speed, ped delay
- Included in all editions since 2010 HCM

## Walkability

- Measures of facility attractiveness to pedestrians
- Adjacent land use, aesthetics, wayfinding, sun/shade, safety/security, functionality
- Not addressed by the HCM



Kittelson & Associates / Kelly Blume



pedbikeimages.org/Dan Burden

# Pedestrian Operations Application Examples

## Designing sidewalk/facility width to accommodate a given number of pedestrians

- Special events (e.g., sports events, concerts, fairs)
- Large city downtowns, cruise ship ports
- Allocating space for business uses (e.g., café seating, outdoor displays)
- Off-street paths

## Providing sufficient space to store and serve pedestrians

- Transit stops
- Pedestrian storage and circulation at signalized intersection street corners
- Pedestrian interactions and platooning while using signalized crosswalks

## Evaluating pedestrian delay

- Likelihood of risky behavior
- Comparing delay by mode, estimating overall person delay



Kittelson & Associates / Paul Ryus

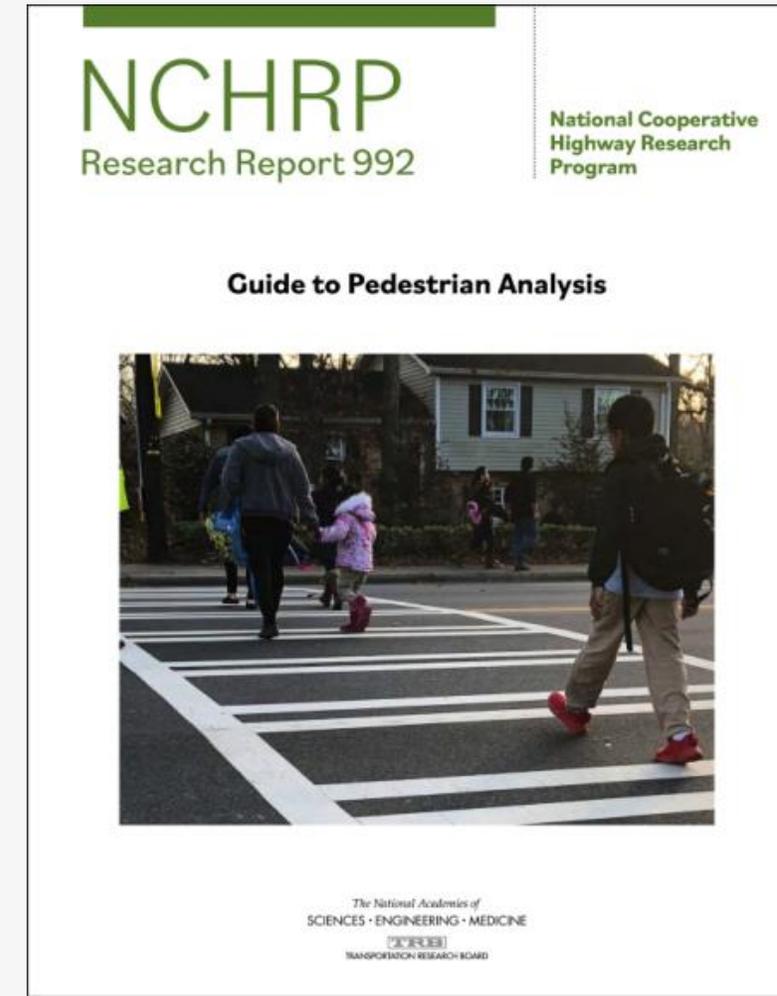


Kittelson & Associates / Paul Ryus

# What's New: Enhancements to Pedestrian Methodologies

## NCHRP Project 17-87

- Project developed by combining two research problem statements
  - “Enhancing Pedestrian Volume Estimation and Developing HCM Pedestrian Methodologies for Safe and Sustainable Communities”



# What's New: Uncontrolled Crossings

## HCM7 Method to estimate average pedestrian (dis)satisfaction making the crossing is sensitive to

- Ability to cross immediately (adequate gap)
- Delay if not able to cross immediately
- Daily traffic (relates to street width/speed)
- Specific crossing treatments
  - Marked crosswalk, median island, RRFB (studied treatments)
- Any treatment that improves yielding or shortens crossing distances will show a satisfaction benefit

Crossing Treatment	Yield Rate (%)		Sample Size (sites)
	Average	Range	
No treatment (unmarked)	24	0–100	37
Crosswalk markings only (any type)	33	0–95	58
Crosswalk markings, plus:			
Pedestal-mounted flashing beacon	26	0–52	2
Overhead sign	35	12–57	2
Overhead flashing beacon (push-button activation)	51	13–91	14
Overhead flashing beacon (passive activation)	73	61–76	29
In-roadway warning lights	58	53–65	11
Median refuge island	60	0–100	21
Pedestrian crossing flags	74	72–80	6
In-street pedestrian crossing signs	76	35–88	20
Rectangular rapid-flashing beacon (RRFB)	82	31–100	64
School crossing guard	86	—	1
School crossing guard and RRFB	92	—	1
Pedestrian hybrid beacon (HAWK)	91	73–99	37
Mid-block crossing signals, half signals	98	94–100	13

# What's New: Signalized Crossing Delay

## HCM7 adds delay estimation methods for additional crossing situations

- One leg in two stages
- Two legs in two stages
- Crosswalk closure (three-leg crossing vs. one-leg)
- Exclusive pedestrian phases
- Coordinated actuated signal with permissive period
- Free signal operation

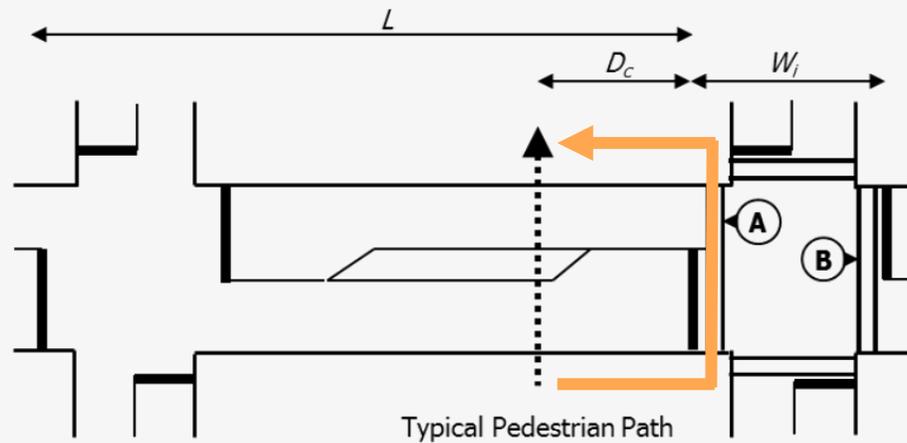
## Pedestrian satisfaction method provided for signalized crossings

- Sensitive to
  - Conflicting traffic volume, traffic speed
  - Pedestrian delay
  - Number of traffic lanes crossed
  - Channelizing island presence

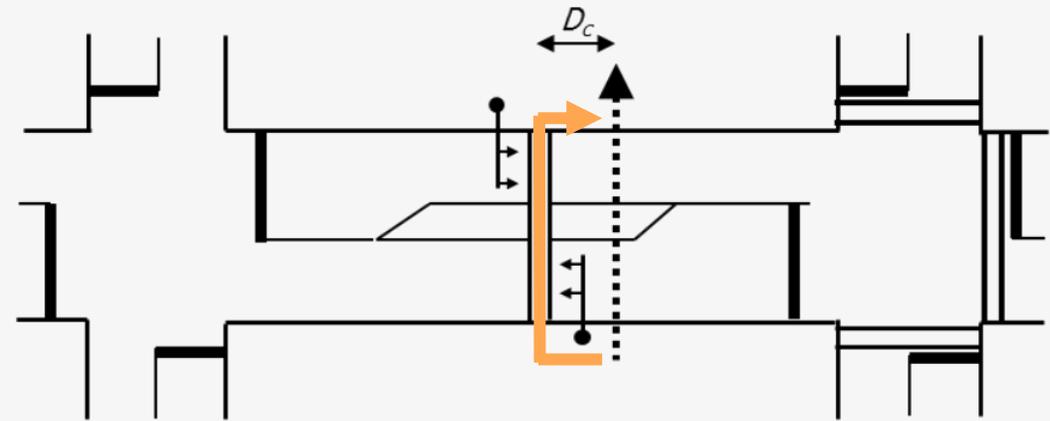


# What's New: Urban Street Pedestrian LOS Method

## HCM7 increased sensitivity to diversion length



(a) Divert to Nearest Boundary Intersection



(b) Divert to Midsegment Signalized Crosswalk

# Summary

## **Multimodal methods are integrated throughout the HCM**

- Encourages analysts to evaluate roadway performance not just for motorized vehicles, but for all roadway users

## **The HCM's multimodal quality of service measures were developed from surveys of user satisfaction**

## **Link, segment, and facility measures can be used to evaluate the reallocating street right-of-way among modes**

- Compare modal index values and LOS to each other to demonstrate the relative amounts of change

## **New uncontrolled pedestrian crossing method is sensitive to the effects of safety countermeasures on ped satisfaction**

## **Free tools available on the online HCM Volume 4 to assist in evaluating multimodal performance and QOS**



# HCM7 Case Study Applications

-

**Dave Stanek**

**HIGHWAY CAPACITY MANUAL**  
7TH EDITION: A GUIDE FOR MULTIMODAL MOBILITY

# New and Updated Methods in 7th Edition of HCM

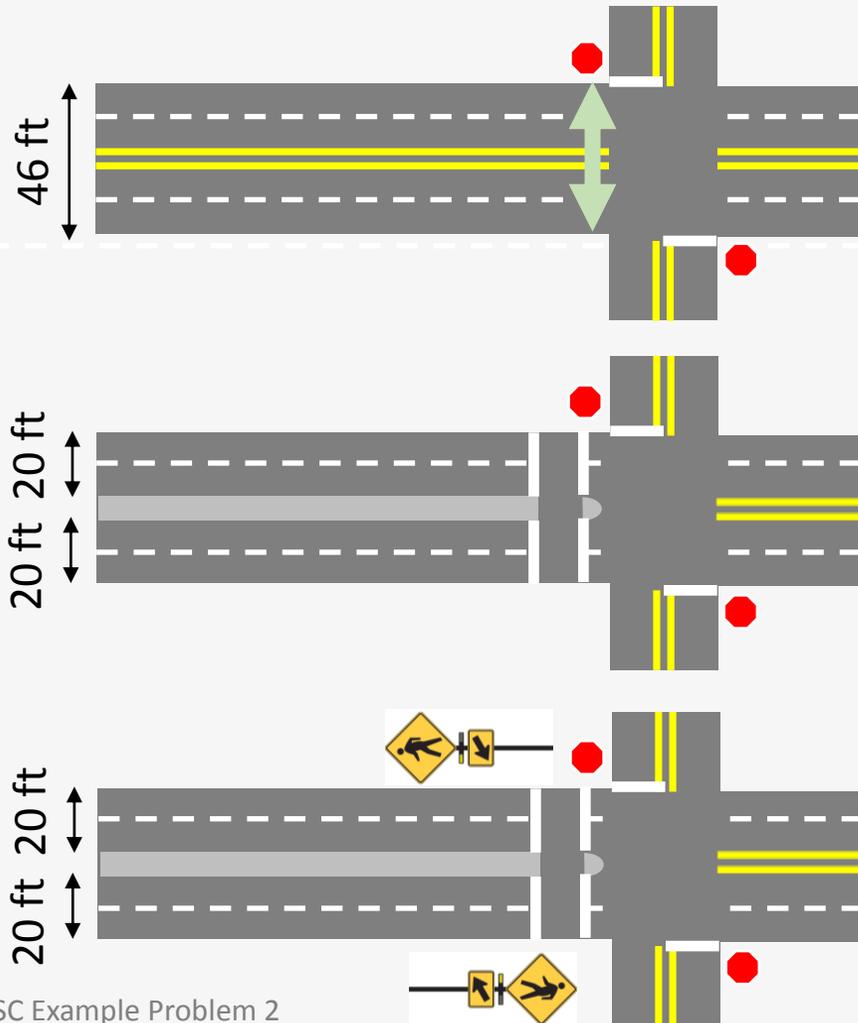
Methods and Applications	New/Updated HCM Chapters
Pedestrian performance for unsignalized and signalized intersections and for urban streets <ol style="list-style-type: none"> <li>1. Uncontrolled pedestrian crossing</li> <li>2. Diagonal pedestrian crossing at a signalized intersection</li> </ol>	Updated Chapters 18, 19, 20, 30, 31 & 32
Capacity adjustment for Connected and Automated Vehicles (CAV) <ol style="list-style-type: none"> <li>3. Freeway planning</li> </ol>	Updated Chapters 26, 31 & 33
Two-lane highway performance <ol style="list-style-type: none"> <li>4. Two-lane highway with horizontal curves</li> </ol>	New Chapter 15
Active Transportation and Demand Management (ATDM) for urban streets	Updated Chapters 17 & 37
Network analysis <ol style="list-style-type: none"> <li>5. Off-ramp queue spillback</li> <li>6. On-ramp queue spillback</li> </ol>	New Chapter 38

# Uncontrolled Pedestrian Crossing



# Uncontrolled Pedestrian Crossing

## Determine Pedestrian LOS for Crossing Treatments



1,700 veh/h (peak hour),  $D = 0.50$ , AADT = 21,250,  
average pedestrians

### Existing:

- Local yielding rate = 0%
- P(delayed crossing) = 99.7%, average delay  $\gg 60$  s
- P(dissatisfaction) = 86.2%  $\rightarrow$  LOS = F

### Marked crosswalk + median island:

- Local yielding rate = 50%
- P(delayed crossing) = 76%, average delay = 6 s
- P(dissatisfaction) = 21%  $\rightarrow$  LOS = C

### Marked crosswalk + median island + RRFB:

- Local yielding rate = 80%
- P(delayed crossing) = 76%, average delay = 3 s
- P(dissatisfaction) = 3%  $\rightarrow$  LOS = A

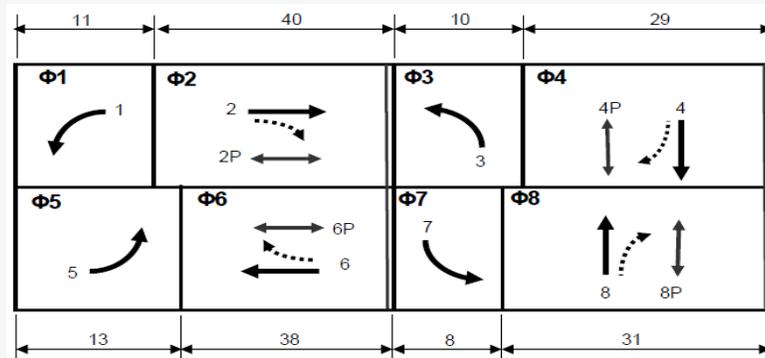
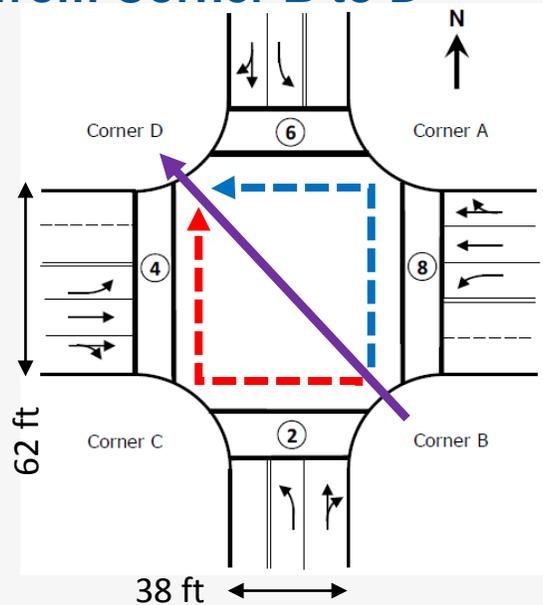
# Diagonal Pedestrian Crossing at a Signalized Intersection



# Diagonal Pedestrian Crossing at a Signalized Intersection

## Determine Travel Time from Corner B to D

- 30% elderly pedestrians  
5 second walk interval
- Actuated signal
- Rest-in-walk not enabled



Phase sequence and durations

## Clockwise route:

- First stage delay = 13.0 sec/ped
- Second stage delay = 37.5 sec/ped
- Two-stage delay = 50.5 sec/ped
- Overall travel time = 80.8 sec/ped

## Counterclockwise route:

- First stage delay = 15.8 sec/ped
- Second stage delay = 24.4 sec/ped
- Two-stage delay = 40.2 sec/ped
- Overall travel time = 70.5 sec/ped

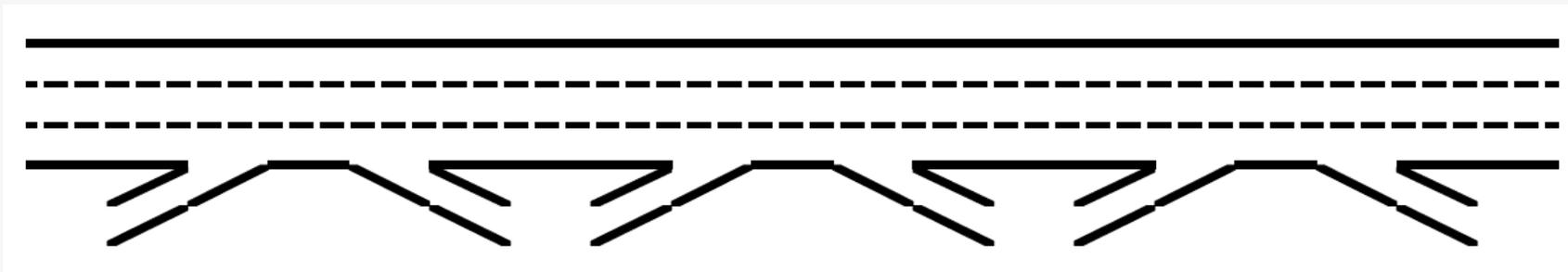
## Diagonal crossing:

- Add 27-second pedestrian only phase
- Pedestrian delay = 49.8 sec/ped
- Overall travel time = 71.9 sec/ped

# Freeway Planning for CAVs

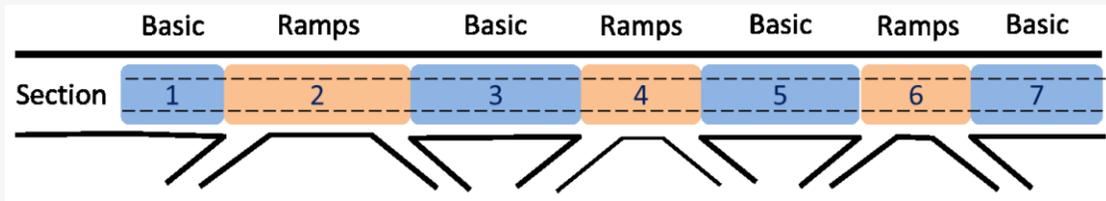


- Long-range planning study
- 5 miles of rural freeway between two communities
- Follow procedure from the *Planning and Preliminary Engineering Applications Guide to the Highway Capacity Manual, NCHRP Report 825*



# Freeway Planning for CAVs

## Determine Lanes Needed to Serve Peak Hour Demand



- Assign sections as Basic and Ramps
- Ramps are assigned 97 or 95% capacity of Basic sections

Peak Hour	1	2	3	4	5	6	7
Capacity	6,651	6,318	6,651	6,318	6,651	6,318	6,651
10 Yr Demand	4,895	5,905	5,554	6,269	5,729	5,894	5,729
20 Yr Demand	5,439	6,561	6,171	6,966	6,366	6,549	6,366
30 Yr Demand	5,983	7,217	6,788	7,663	7,003	7,204	7,003

	10 Yr	20 Yr	30 Yr
CAV Percentage	10%	25%	50%

## Demand to Capacity Ratios without CAVs

	1	2	3	4	5	6	7
10 Years	0.74	0.93	0.84	0.99	0.86	0.93	0.86
20 Years	0.82	1.04	0.93	1.10	0.96	1.04	0.96
30 Years	0.90	1.14	1.02	1.21	1.05	1.14	1.05

## Demand to Capacity Ratios with CAVs

	1	2	3	4	5	6	7
10 Years	0.73	0.93	0.83	0.98	0.85	0.92	0.85
20 Years	0.79	1.01	0.89	1.07	0.92	1.00	0.92
30 Years	0.79	0.97	0.89	1.03	0.92	0.97	0.92

With CAVs, only Section 4 would need 4 lanes to serve peak hour demand in 30-Year scenario.

# Two-lane Highway with Horizontal Curves

Passing Constrained



Passing Zone



Passing Lane



# Two-lane Highway with Horizontal Curves

## Determine LOS Before and After Detour Route

Segment	Horizontal Class	Vertical Class	Posted Speed Limit (mi/h)	Directional Volume (veh/h)	Opposing Volume (veh/h)	Peak Hour Factor	Heavy Vehicles (%)
1	1	1	55	850	*	0.94	8
2	1	1	55	825	*	0.95	8
3	1	1	55	820	*	0.95	8
4	1	1	55	800	500	0.94	7.5
5	1	1	55	795	*	0.935	8

- Level roadway
  - 12 ft lane width
  - 6 ft shoulder width
  - No access points
- Detour route in Segment 5:
- 4 500-ft radius curves of 500 ft each with 0% superelevation

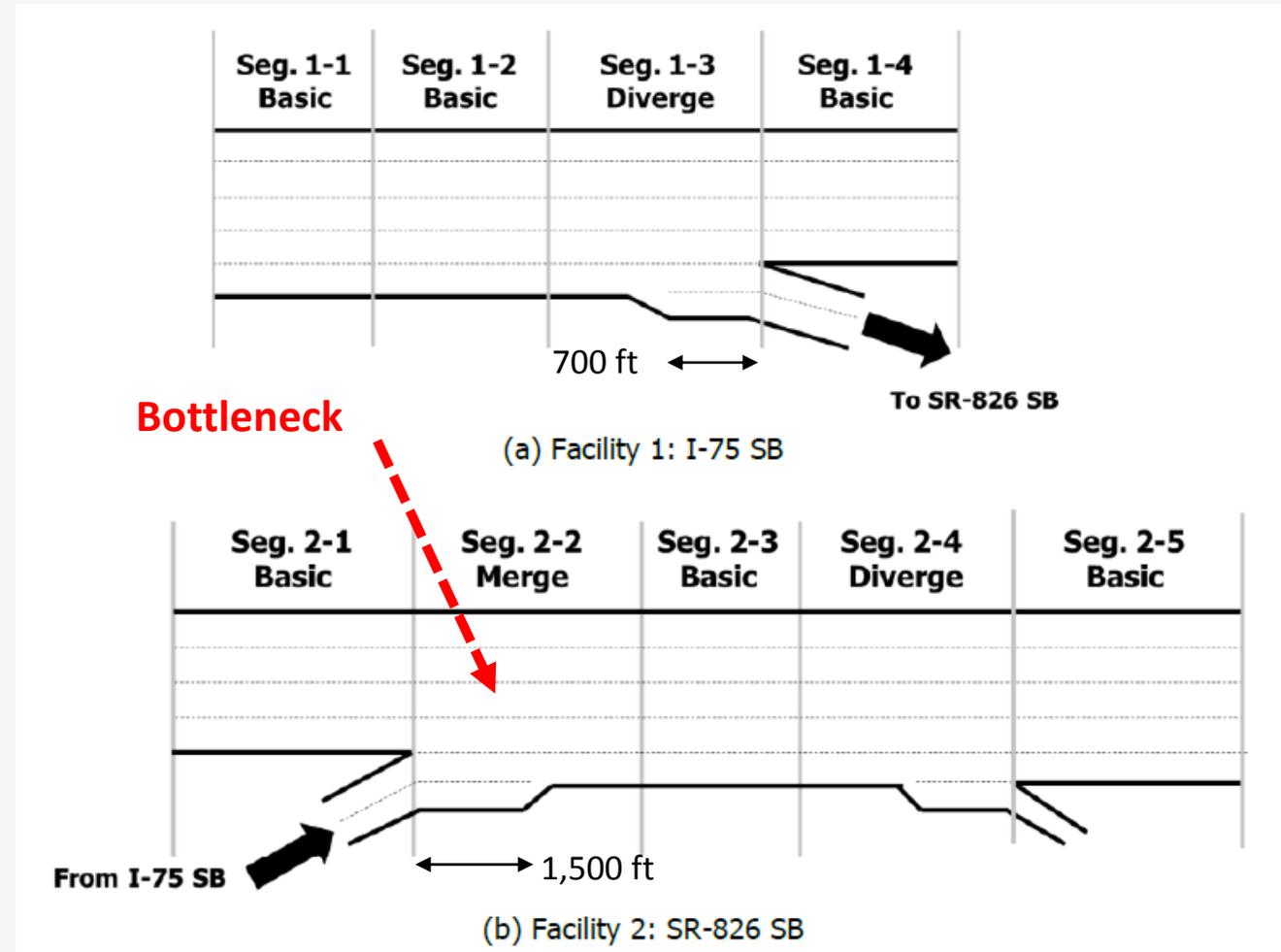
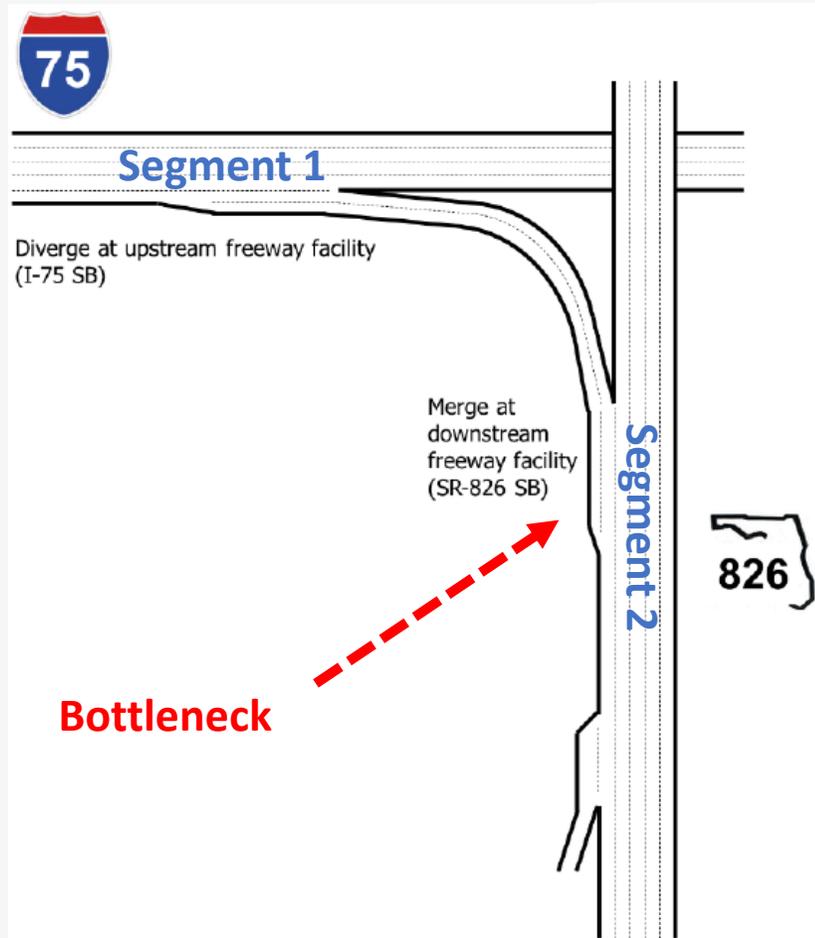
## Before Detour Route:

Segment	Length (mi)	Type	Follower Density (followers/mi)	LOS
1	0.75	Passing Constrained	10.7	D
2	1.50	Passing Lane	2.9	B
3	1.00	Passing Constrained	8.2	D
4	0.50	Passing Zone	8.2	D
5	1.75	Passing Constrained	8.8	D
5.50 Facility			7.3	C

## After Detour Route:

- Segment 5 average speed decreases from 58.9 to 54.7 mph
- Follower density increases from 8.8 to 9.0 followers/mi
- Segment 5 LOS remains at LOS D
- Facility LOS remains at LOS C

# Off-ramp Queue Spillback



# Off-ramp Queue Spillback

## Determine Maximum Queue Length

Analysis Period	Freeway Facility 1 (I-75 SB)		Freeway Facility 2 (SR-826 SB)	
	Mainline Demand Flow Rate (veh/h)	Diverge Demand Flow Rate (veh/h)	Mainline Demand Flow Rate (veh/h)	Merge Demand Flow Rate (veh/h)
1	5,400	1,400	4,000	1,400
2	6,200	3,000	5,700	3,000
3	6,000	3,400	5,600	3,400
4	4,500	800	4,500	800

## Isolated corridor LOS (Chapter 25 Freeway Facilities)



Analysis Period	Segment ID and Type			
	1-1 Basic	1-2 Basic	1-3 Diverge	1-4 Basic
1	C	C	B	B
2	C	C	C	A
3	C	C	C	A
4	B	B	A	B

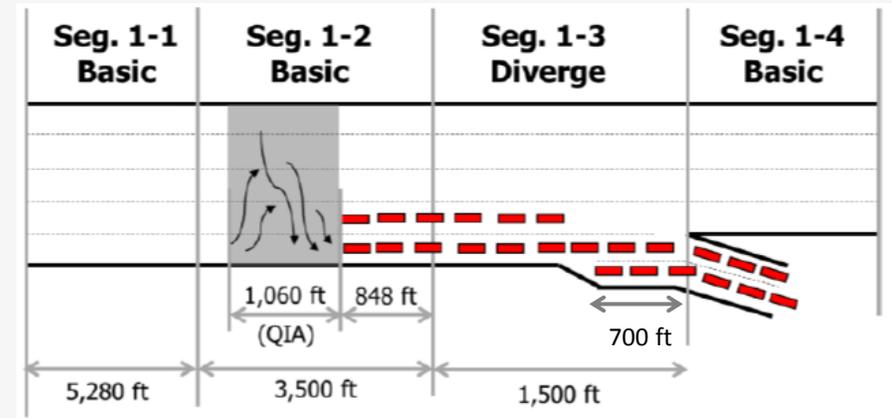


Analysis Period	Segment ID and Type				
	2-1 Basic	2-2 Merge	2-3 Basic	2-4 Diverge	2-5 Basic
1	B	C	C	B	C
2	C	F	E	F	E
3	C	F	F	F	E
4	C	C	C	C	C

## SR 826 On-ramp Queue Length (Chapter 25 Freeway Facilities)

Analysis Period	Total Number of Queued Vehicles [A]	Number of Queued Vehicles in each Lane [B] = [A]/2	Average Vehicle Spacing (ft) [C]	Queue Length (ft) [D] = [B] x [C]	Ramp Length (ft) [E]	Queue Storage Ratio [F] = [D]/[E]	Spillback Occurs?
1	0.0	0.00	—	0		0.00	No
2	38.3	19.15	62	1,188	3,588	0.33	No
3	159.1	79.55	65	5,160		<b>1.44</b>	<b>Yes</b>
4	0.0	0.00	—	0		0.00	<b>Yes</b>

Back of Queue for Analysis Period 3 (Chapter 38)



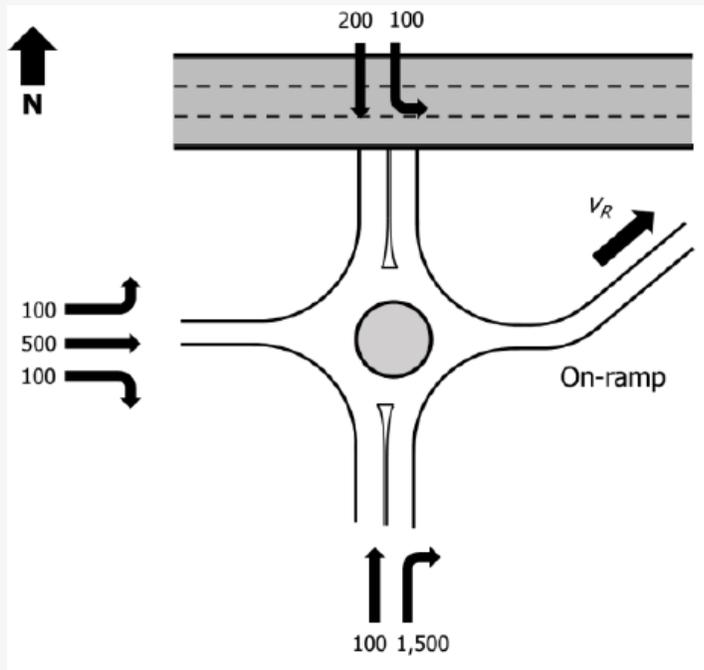
# On-ramp Queue Spillback



# On-ramp Queue Spillback

## Determine Maximum Queue Length

- On-ramp demand is 2,100 pc/h
- Roundabout exit capacity is 1,300 pc/h
- Ramp meter limits on-ramp throughput to 800 pc/h
- Ramp length is 1,657 ft



Isolated analysis results for 15-minute analysis period

Approach	Circulating Flow Rates (pc/h)	Entry Flow Rates (pc/h)	Capacity (pc/h)	Volume-to-Capacity Ratio	95th Percentile Queues (veh)
SB	0	300	1,380	0.22	1
EB	300	700	1,016	0.69	6
NB	700	1,600	676	2.37	121

Note: SB = southbound, EB = eastbound, NB = northbound.

Queue length including on-ramp spillback

Approach	95th Percentile Queues (veh)		
	Isolated	Spillback	Total
SB	1	3	4
EB	6	17	23
NB	121	22	142

---

**Where do we go from here?**

-

**Bastian Schroeder**

## Now that HCM 7 is here, what's next?

- ✓ Publish HCM7
- ✓ Move Manual to Digital version
- ✓ Revamped committee structure to reflect changing industry
- Continued consideration of new research
- Focus on Application
- Big Data, Simple Methods
- Looking beyond the peak hour



## Ongoing/Active Research Impacting Future Releases of HCM

**NCHRP 03-133** Traffic Signal Design and Operations Strategies for Non-Motorized Users

**NCHRP 07-26** Update to HCM Merge, Diverge, and Weaving Methods

**NCHRP 15-66** Arterial Weaving Methodology

**NCHRP 03-130** Guide for Roundabouts

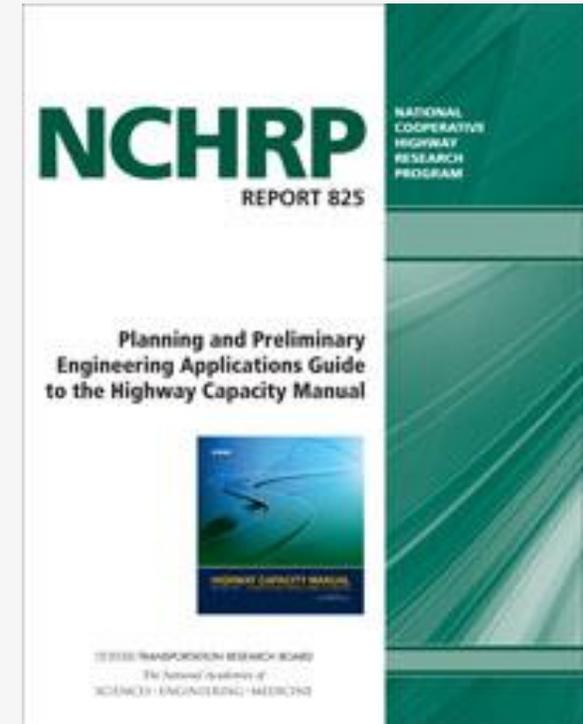
**NCHRP 08-135** Reliability and Quality of Service Evaluation Methods for Rural Highways

**NCHRP 17-98** Guide for Intersection Control Evaluation

**NCHRP 03-136** Estimation of Right-Turn-on-Red Operations

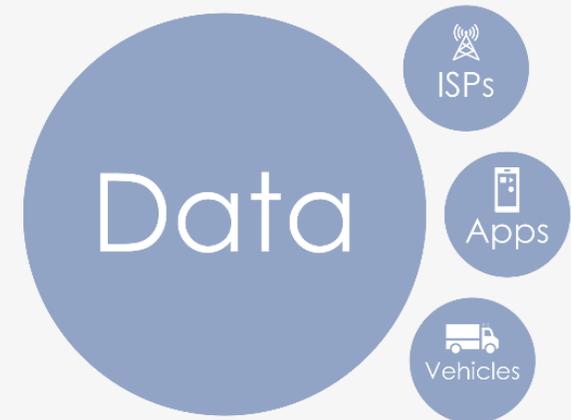
## Focus on Applications

- Have some methods become too complex to apply in practice?
- Limited success of companion applications guides
  - HCM Applications Guidebook (NCHRP Project 3-64, 2006)
  - Planning and Preliminary Engineering Applications Guide to the HCM (NCHRP Report 825, 2016)
- More real-world, case study examples needed plus outreach focused on application
- Back-to-Basics: Providing basic capacity estimates directly in the HCM without having to run software



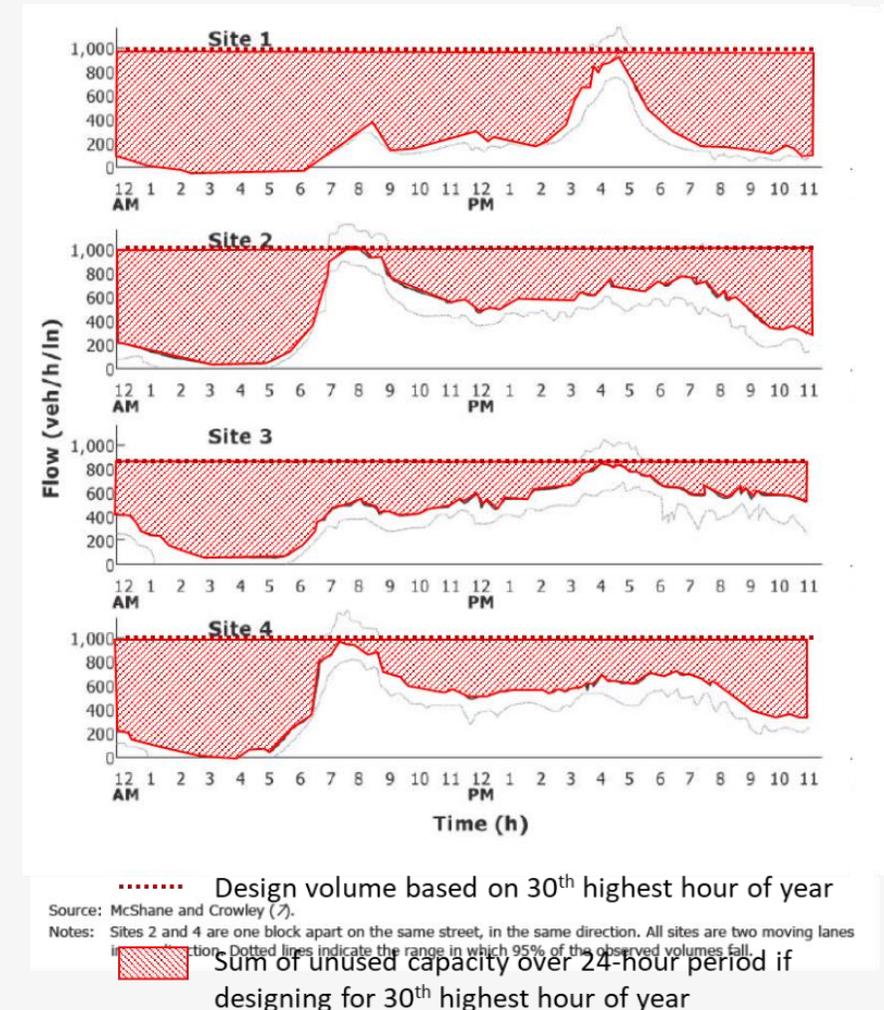
# Big Data, Simple Methods

- Big Data are becoming ubiquitous in transportation field
  - ATSPM, Telematics, Sensors, Crowdsourcing, ...
- More data should not mean more complexity in methods
- Back-to-basics approach for HCM methods
  - Can we use big data sources to more broadly estimate capacity effects of various planning, design and operations scenarios?
- All HCM computations should be doable by hand



## Looking beyond the peak hour

- The HCM (and the profession) has traditionally looked at the peak 15 minutes of the 30<sup>th</sup> highest hour of the year
- Starting to consider side-effects of a capacity-focused approach to planning
- Align the HCM with Safe Systems principles
- Re-frame HCM guidance to assess operations for all users during all hours of the day



## Questions and Contact Information



**Bastian Schroeder, PhD, PE**  
Kittelson and Associates  
[bschroeder@kittelson.com](mailto:bschroeder@kittelson.com)



**Alexandra Kondyli**  
University of Kansas  
[akondyli@ku.edu](mailto:akondyli@ku.edu)



**Behzad Aghdashi, PhD, PMP**  
McTrans Center  
[saghdashi@ufl.edu](mailto:saghdashi@ufl.edu)



**Dan Cook, PE**  
HDR  
[Dan.Cook@hdrinc.com](mailto:Dan.Cook@hdrinc.com)



**Ana Moreno, PhD**  
Technical University of Munich  
[ana.moreno@tum.de](mailto:ana.moreno@tum.de)



**David Stanek, PE**  
Fehr and Peers  
[D.Stanek@fehrandpeers.com](mailto:D.Stanek@fehrandpeers.com)