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# TRB Webinar: Incorporating a Complex Transportation System in the New HCM7

*August 3, 2022*

*1:30 – 3:00PM*



# PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Beth Ewoldsen at [TRBwebinar@nas.edu](mailto:TRBwebinar@nas.edu)

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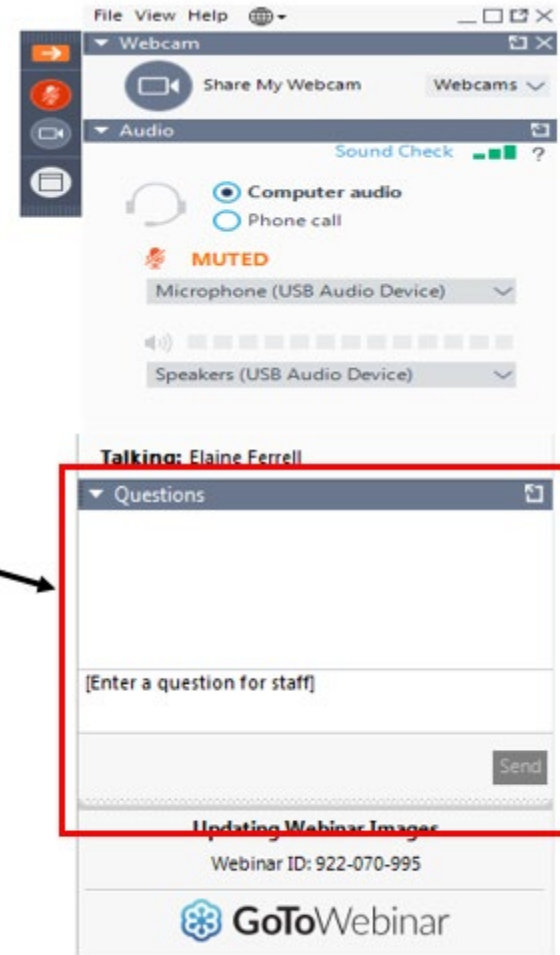
REGISTERED CONTINUING EDUCATION PROGRAM

# Learning Objectives

- Identify potential applications and tools for the HCM7's pedestrian and bicycle methods
- Judge potential impacts of connected and autonomous vehicles (CAVs) on roadway capacity

# Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



# Today's presenters

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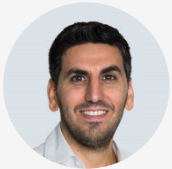
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*Kittelson and Associates*

# Highway Capacity Manual Incorporating a Complex Transportation System in the New HCM7



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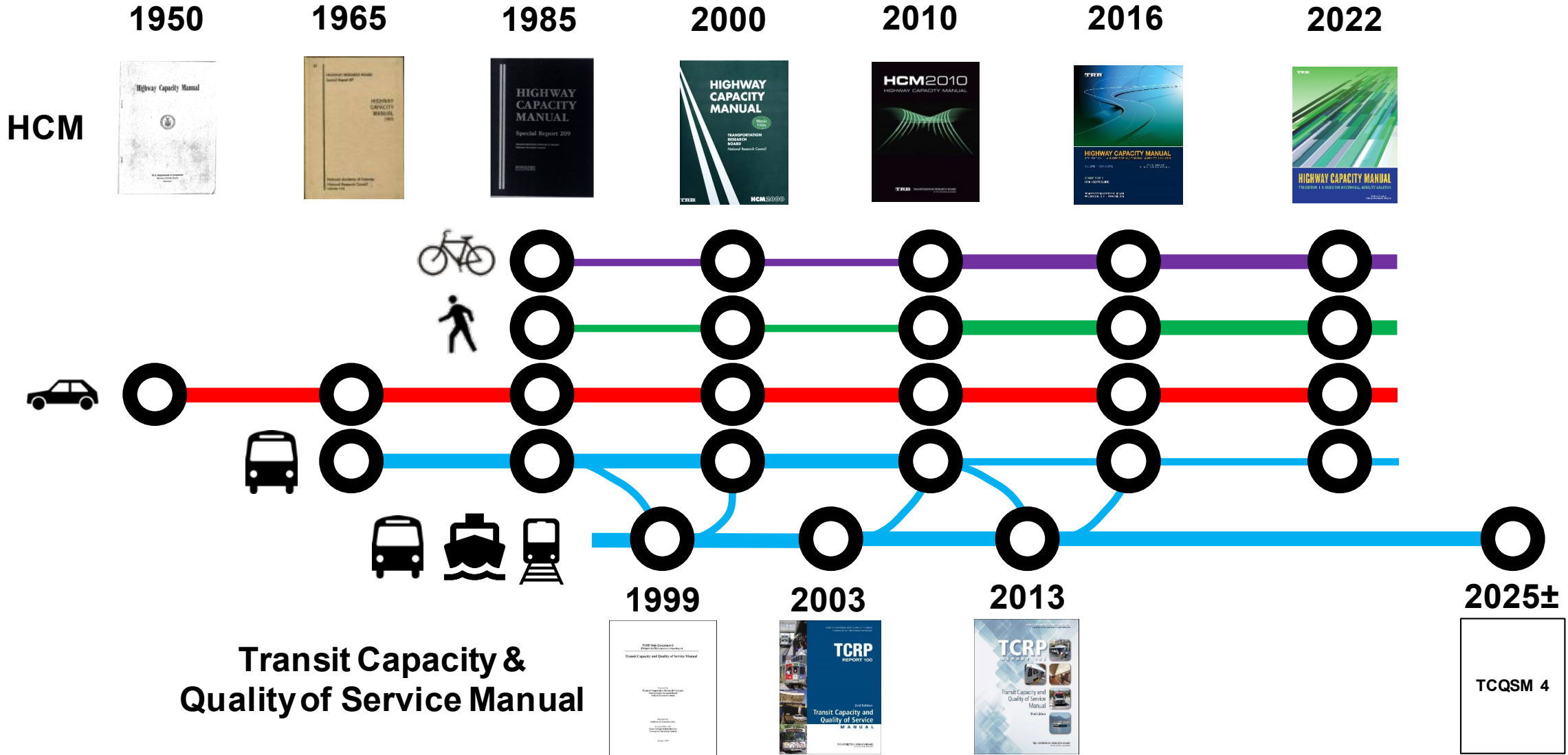
# Agenda

- Overview of HCM multimodal methods
- HCM multimodal method application examples
- Connected and automated vehicles (CAVs)



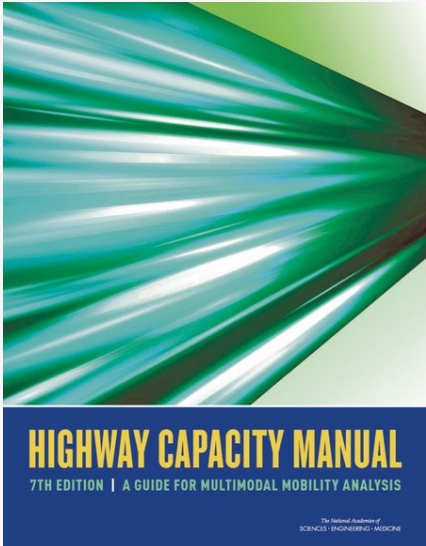
# Overview of HCM Multimodal Methods

# Evolution of HCM Multimodal Methods



# Multimodal Material Is Integrated Throughout HCM7

## Printed HCM & ePub

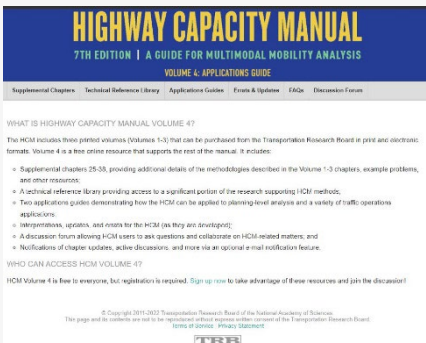


**Volume 1:  
Concepts**

**Volume 2:  
Uninterrupted Flow**

**Volume 3:  
Interrupted Flow**

## Online & ePub



**Volume 4:  
Applications Guide**

3. Modal Characteristics
4. Traffic Operations and Capacity Concepts
5. Quality-of-Service Concepts

15. Two-Lane Highways (also used for multilane highways)

16. Urban Street Facilities
18. Urban Street Segments
19. Signalized Intersections
20. Two-Way Stop-Controlled Intersections
24. Off-Street Pedestrian and Bicycle Facilities

26. Freeway & Highway Segments: Supplemental
29. Urban Street Facilities: Supplemental
30. Urban Street Segments: Supplemental
31. Signalized Intersections: Supplemental
32. Stop-Controlled Intersections: Supplemental
35. Pedestrians and Bicycles: Supplemental

# 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



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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



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## Pedestrian Operations Influences Safety

- **Persons spill out of the sidewalk circulation zone before the sidewalk's capacity is reached**
  - For example, walking in the street to get around slower pedestrians
- **Likelihood of crossing against the traffic signal increases as pedestrian delay increases**
  - Very likely to comply with signals when expected delay is  $\leq 10$  seconds
  - Pedestrians become impatient when delays  $> 30$  seconds
- **Similar (non-HCM) methods used in building & passenger facility design**
  - For example, time required to clear a subway platform and get passengers out of the station in case of fire



## 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



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Kittelson & Associates/ Dorrett Oosterhoff

## Bicycle Operations Applications 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



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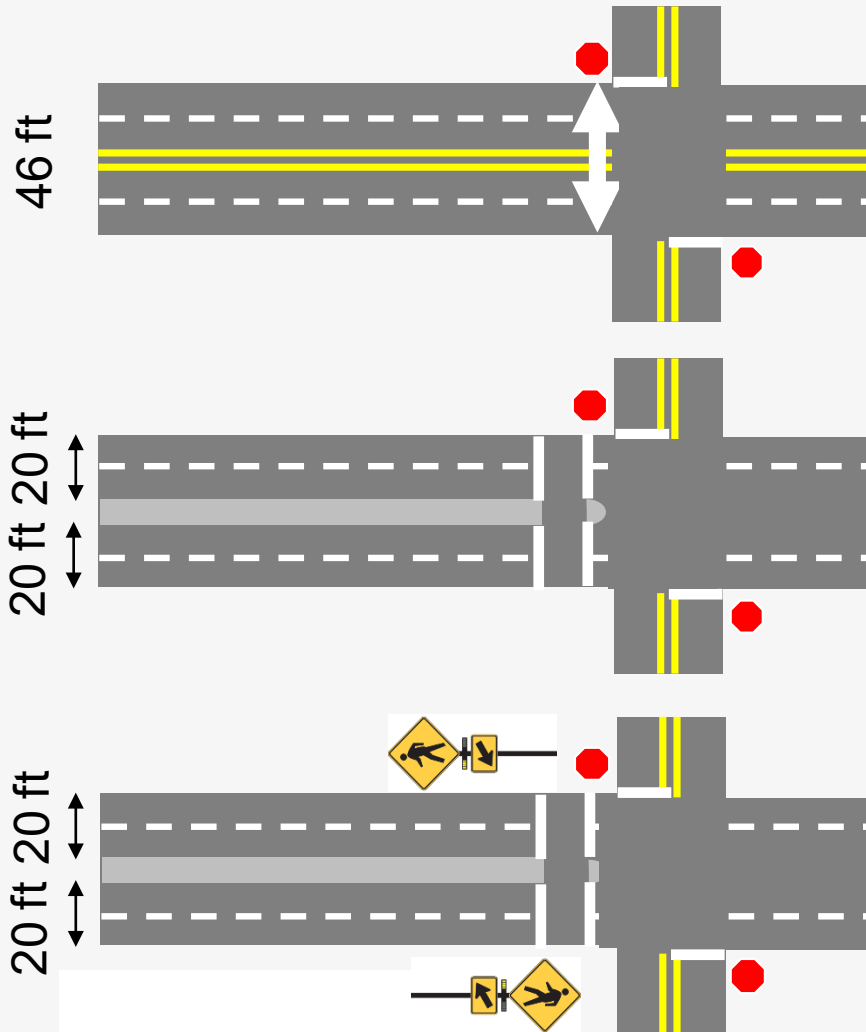
# HCM Multimodal Method Applications Examples

# Uncontrolled Pedestrian Crossings

- **Updated method in HCM7**
  - Method estimates the percentage of pedestrians who would say they would be dissatisfied making the crossing
    - Developed from field surveys and video observations of pedestrians making actual trips
  - Sensitive to:
    - Hourly and daily traffic volumes
    - Motorist yielding rate
    - Specific crossing treatments (marked crosswalk, median island, RRFB)
  - Delay is also calculated and is sensitive to the design pedestrian (assumed pedestrian speed)



# Uncontrolled Pedestrian Crossings



- 1,700 veh/h (peak hour), 50/50 directional split, AADT = 21,250, average ped
- **Existing crossing:**
  - Locally measured yielding rate = 0%
  - P(delayed crossing) = 99.7%, average delay >> 60 s
  - P(dissatisfaction) = 86% → LOS = F
- **Add median island and crosswalk markings:**
  - Locally measured yielding rate = 50%
  - P(delayed crossing) = 76%, average delay = 6 s
  - P(dissatisfaction) = 21% → LOS = C
- **Also add rectangular rapid-flashing beacons (RRFBs):**
  - Locally measured yielding rate = 80%
  - P(delayed crossing) = 76%, average delay = 3 s
  - P(dissatisfaction) = 3% → LOS = A

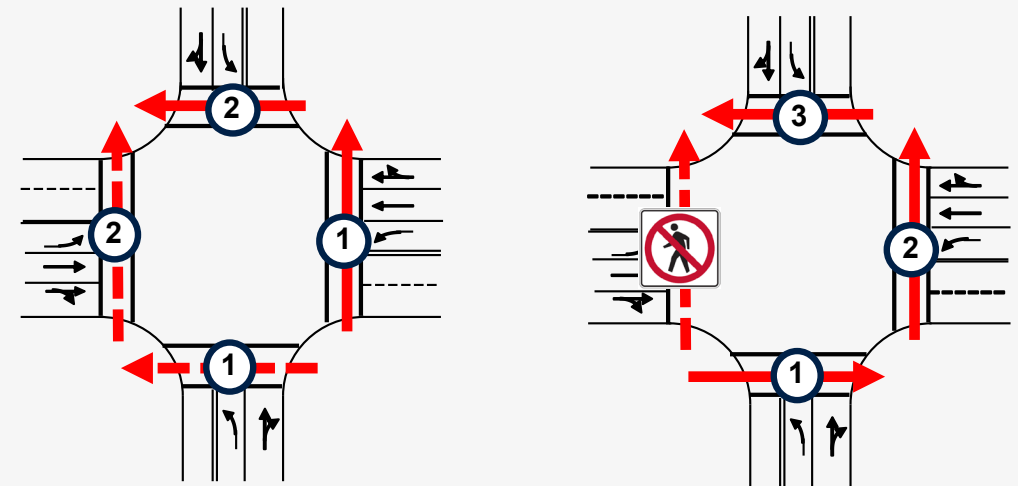
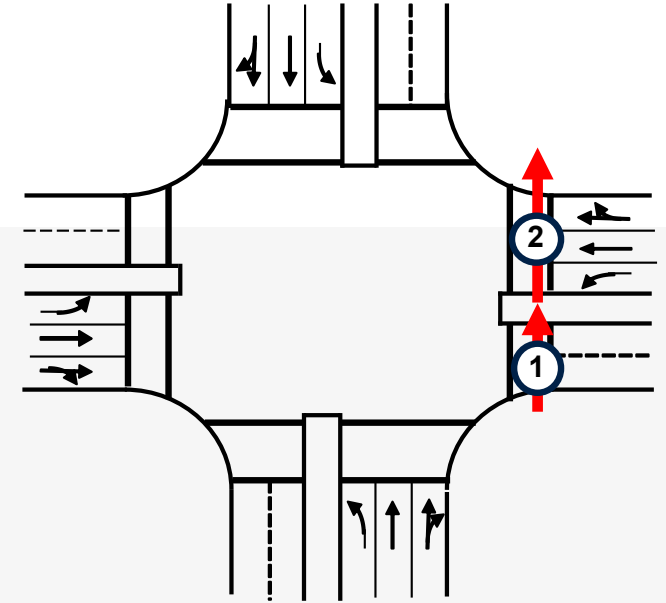
# Uncontrolled Pedestrian Crossings

- **Can compare potential crossing treatments on the basis of**
  - Safety (NCHRP Project 17-84, future HSM 2)
  - Pedestrian delay (HCM7)
  - Pedestrian satisfaction (HCM7)
  
- **HCM7 incorporates the most recent information about yielding rates for different crossing countermeasures**
  - National averages
    - Varies by location (e.g., speed, driver culture, enforcement practices, ped activity)
  - Use local yielding rates when available

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

## Signalized Pedestrian Crossings

- **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



# Walking & Biking Along Streets

Links



Image © 2016 Google

Segments



Image © 2016 Google

# Walking & Biking Along Streets and Paths

Facilities

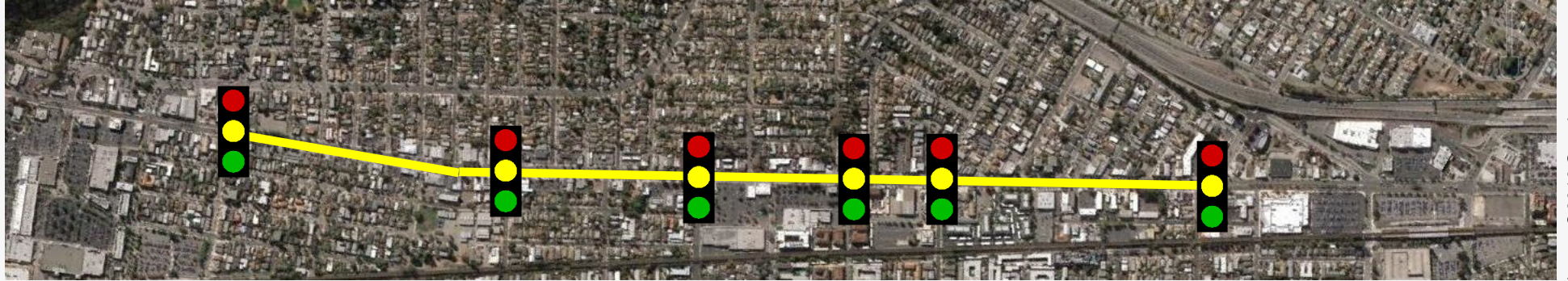


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Off-street  
Pathways

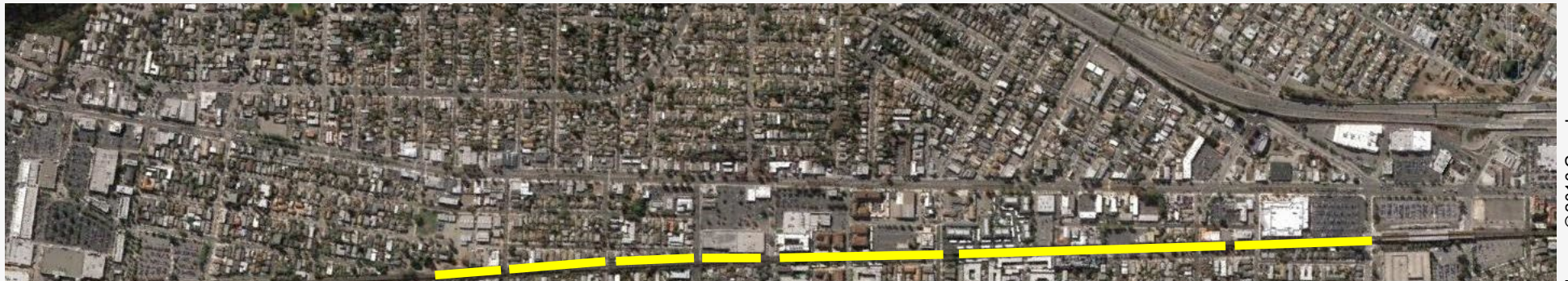


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## Multimodal Performance Measures: Streets

- **Quality of service**
  - Pedestrian and bicycle LOS indexes predict how modal users would rate their experience (1 = best, 6 = worst)
  - Pedestrian and bicycle index values are directly comparable to each other
  - Index values can be used as-is and/or converted to a LOS letter (A-F)
  - Transit index value based on how ridership changes in response to changes in QOS (e.g., frequency, crowding, reliability)
- **Operations**
  - Pedestrians: average pedestrian space, average travel speed
  - Bicycles: average travel speed
  - Transit: average travel speed



## Multimodal LOS Index Factors

- **Pedestrians**
  - Sidewalk width (no sidewalk = 0 ft)
  - Separation from traffic (including landscape buffers, bike lanes, parking lanes, and shoulder when present)
  - Motorized vehicle volume and speed
  - On-street parking presence and occupancy, physical buffer presence (e.g., street trees, bollards)
- **Bicycles**
  - Bicycle lane or shoulder width
  - Outside travel lane width
  - On-street parking presence and occupancy
  - Motorized vehicle volume and speed
  - Percentage heavy vehicles in the traffic stream (trucks, buses)
  - Pavement condition

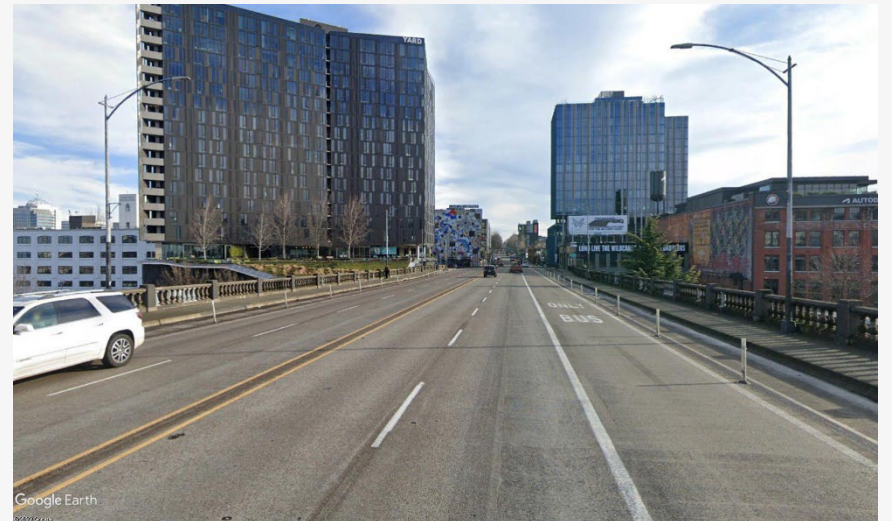


## Street Cross-Section Reallocation

- **Burnside Bridge, Portland, OR**
- **2014**
  - 6-foot sidewalk
  - 6-foot bicycle lane
  - Three 12-foot lanes eastbound
  - 1,932 veh/h eastbound, posted speed = 30 mph
  - 11 buses/hour, all seats full
- **2022**
  - 6-foot sidewalk
  - 6-foot bicycle lane with 1.5-foot buffer
  - 10.5-foot bus lane
  - Two 10.5-foot travel lanes
  - For sake of example, all other values unchanged



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## Street Cross-Section Reallocation

- **2014**
  - Automobiles: 18.3 mph average speed (including signal delay) = LOS C
  - Pedestrians: LOS score = 3.17 = LOS C
  - Bicycles: LOS score = 2.80 = LOS C
  - Buses: 10.9 mph average speed, LOS score = 2.40 = LOS B
- **2022**
  - Automobiles: 10.3 mph average speed = LOS F
  - Pedestrians: LOS score = 1.33 = LOS A
  - Bicycles: LOS score = -5.42 = LOS A
  - Buses: 12.9 mph average speed, LOS score = 1.91 = LOS A



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## Multimodal Performance Measures: Off-Street Paths

- **Pedestrians on exclusive pedestrian facilities**
  - Average pedestrian space and speed on walkways
  - Average pedestrian space on stairs
- **Pedestrians on shared-use paths**
  - Rate of bicycle meeting & passing events
- **Bicycles on shared-use paths**
  - Bicycle LOS score
    - Rate of meeting & passing other path users
    - Centerline presence
    - Path width
    - Delayed passing rate





## 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**

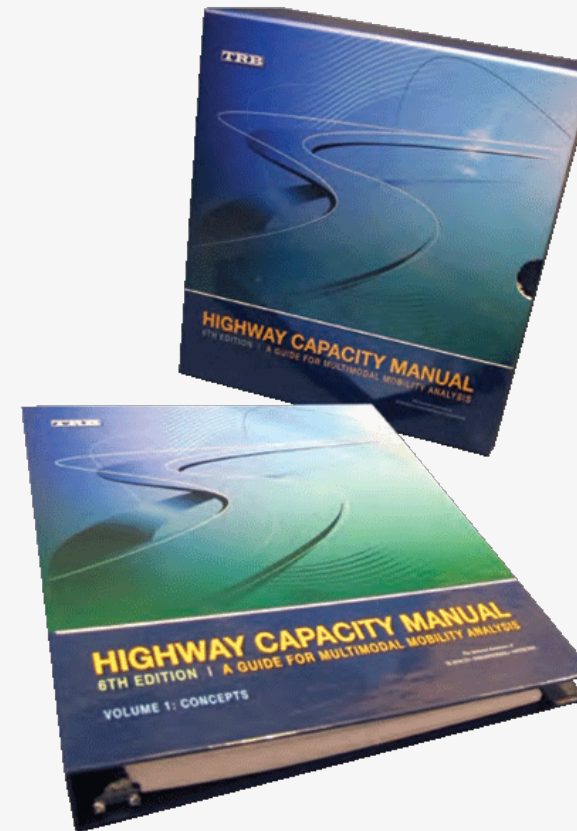




**Methods and Applications for  
Connected and Automated Vehicles (CAVs)**

## HCM Context and Project Motivation

- HCM traditionally used for capacity analysis and planning studies
- Agencies looking for answers about the impacts of CAVs on future capacities
- Results from this study have been integrated into the HCM Version 7.0



## Research Overview



### Objectives

- Develop capacity adjustment factors for CAVs at different levels of volume and market penetration rate



### Modeling Approach

- “Agent-based” approach
- Vehicle and driver behavior fully customizable for simulation scenarios to capture CAVs

# Automated Vehicles (AV) versus Connected and Automated Vehicles (CAV)

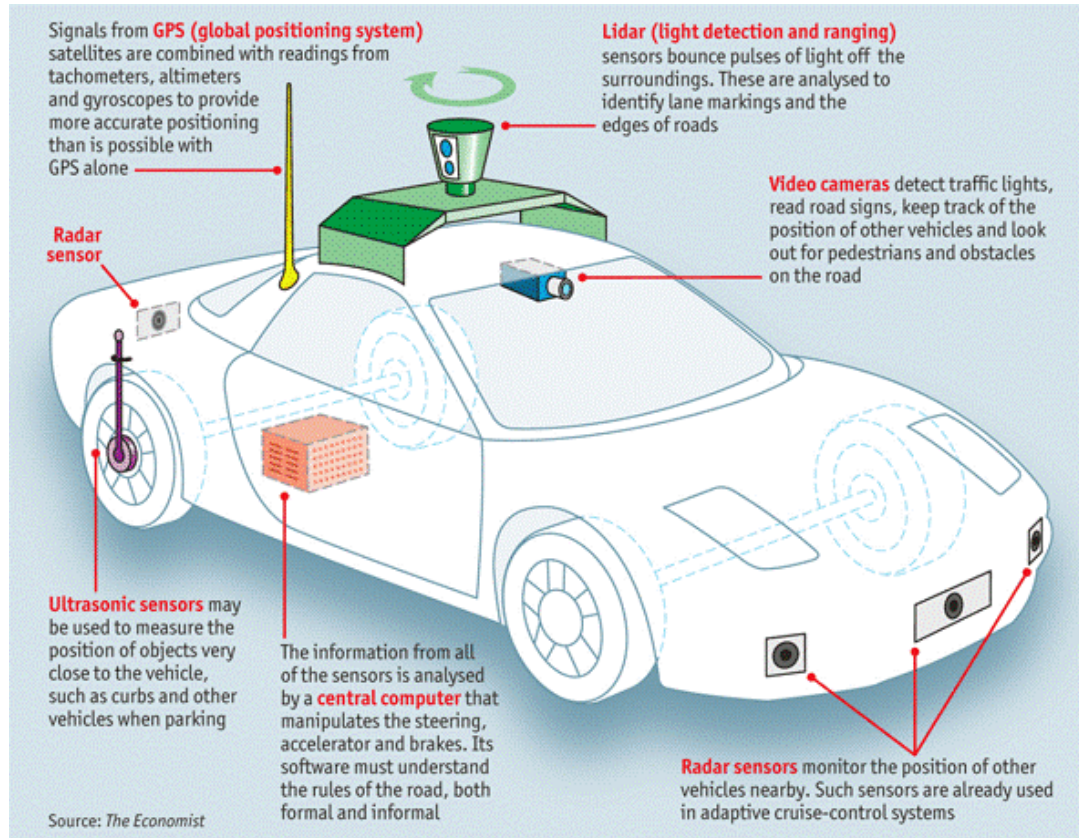


Image Credit: *The Economist*

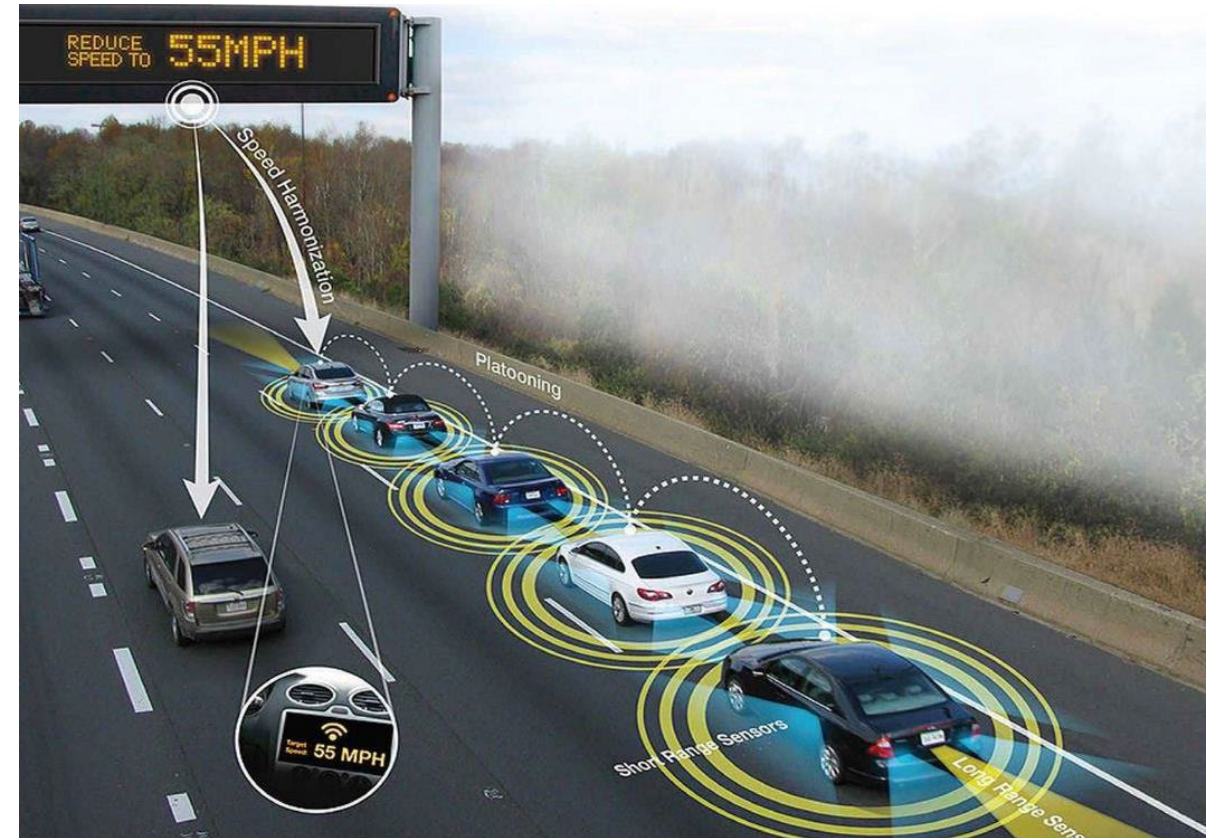
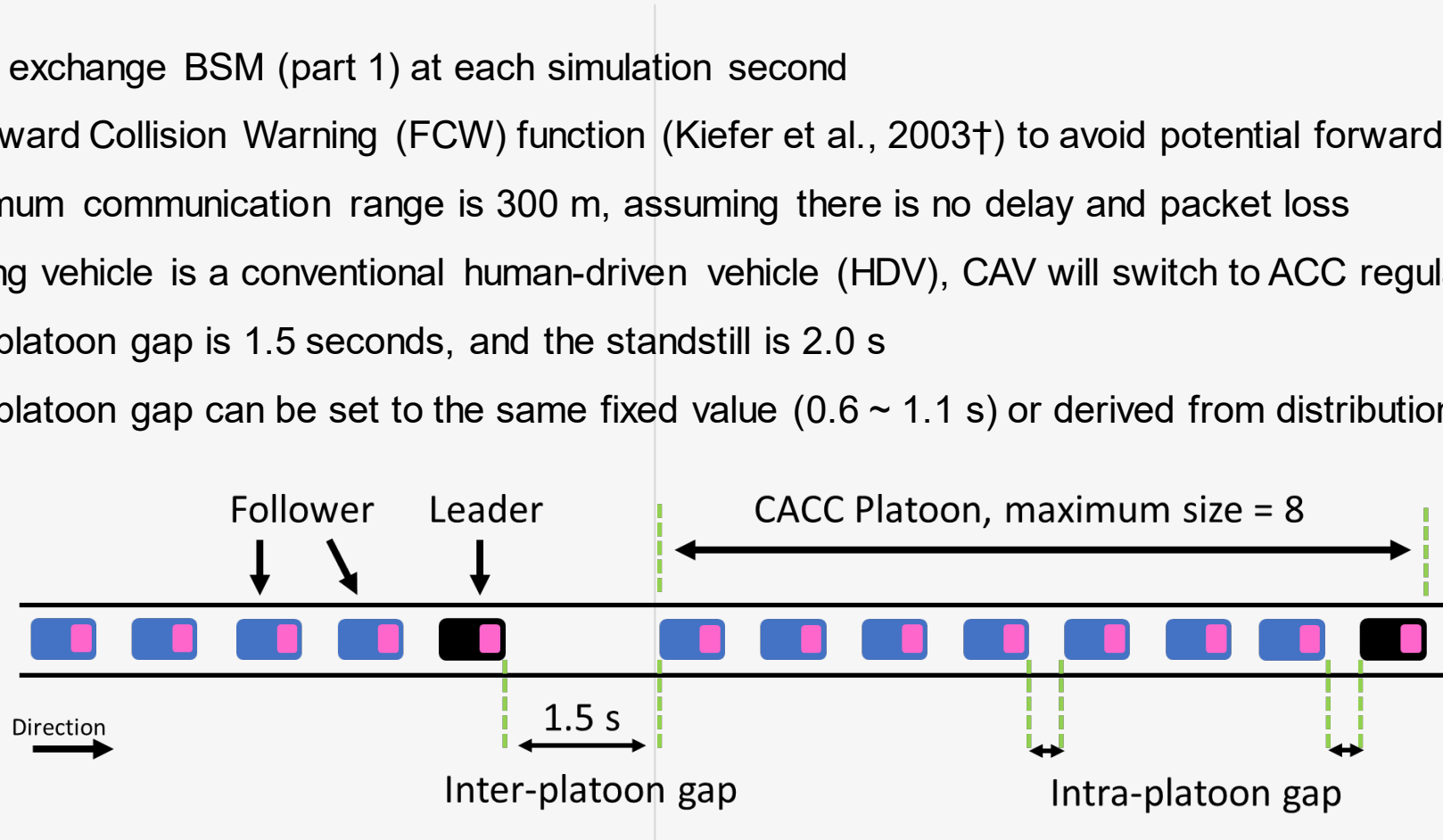


Image Credit: *PCQuest*

## CAV and Platoon Assumptions

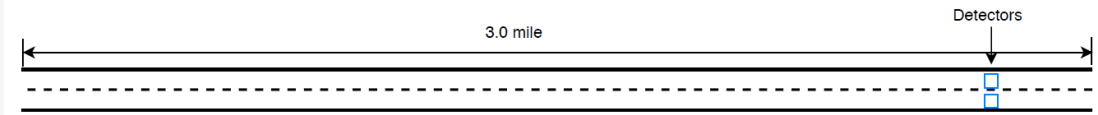
- CAVs can exchange BSM (part 1) at each simulation second
- Using Forward Collision Warning (FCW) function (Kiefer et al., 2003<sup>†</sup>) to avoid potential forward collision
- The maximum communication range is 300 m, assuming there is no delay and packet loss
- If preceding vehicle is a conventional human-driven vehicle (HDV), CAV will switch to ACC regulation mode
- The inter-platoon gap is 1.5 seconds, and the standstill is 2.0 s
- The intra-platoon gap can be set to the same fixed value (0.6 ~ 1.1 s) or derived from distribution



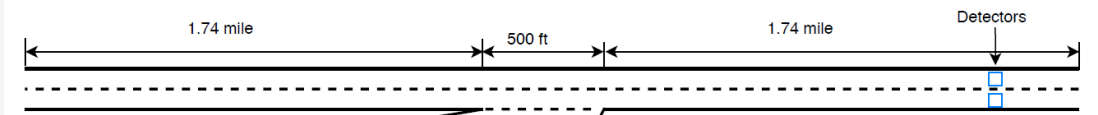
<sup>†</sup> Kiefer, R. J., et al., Forward collision warning requirements project: refining the CAMP crash alert timing approach by examining "last second" braking and lane change maneuvers under various kinematic conditions. No. DOT HS 809 574. United States. NHTSA, 2003.

## Segment Types Analyzed

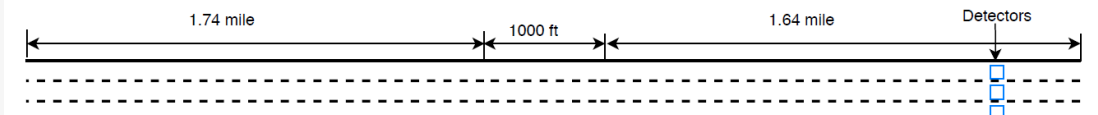
- Freeway segments
  - Basic
  - Merge
  - Diverge
  - Weave
- Signalized intersections
  - Protected only phases
  - Protected and permitted phases
- Roundabouts
  - Single lane
  - Two-lane
- Two-way stop-controlled intersection (TWSC)



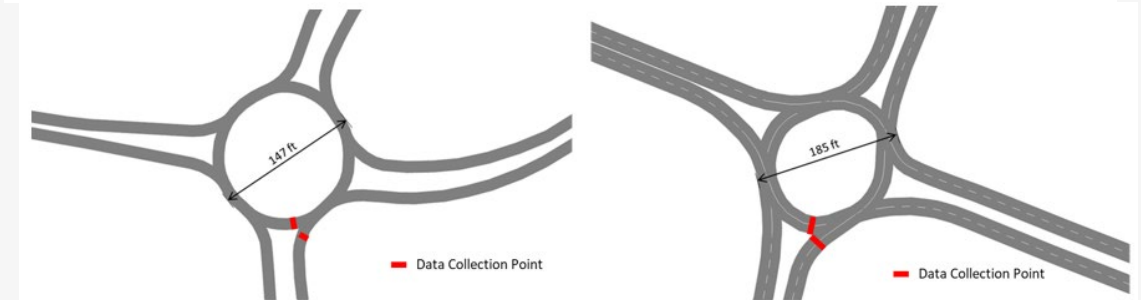
(a) Sketch of basic freeway segment with detectors



(b) Sketch of freeway merge segment with detectors



(c) Sketch of freeway weaving segment with detectors



(a) Sketch of single-lane roundabout

(b) Sketch of two-lane roundabout

# Updates in HCM7

## Chapter 26

Freeway Facility Supplemental

## Chapter 31

Signalized Intersections Supplemental

## Chapter 33

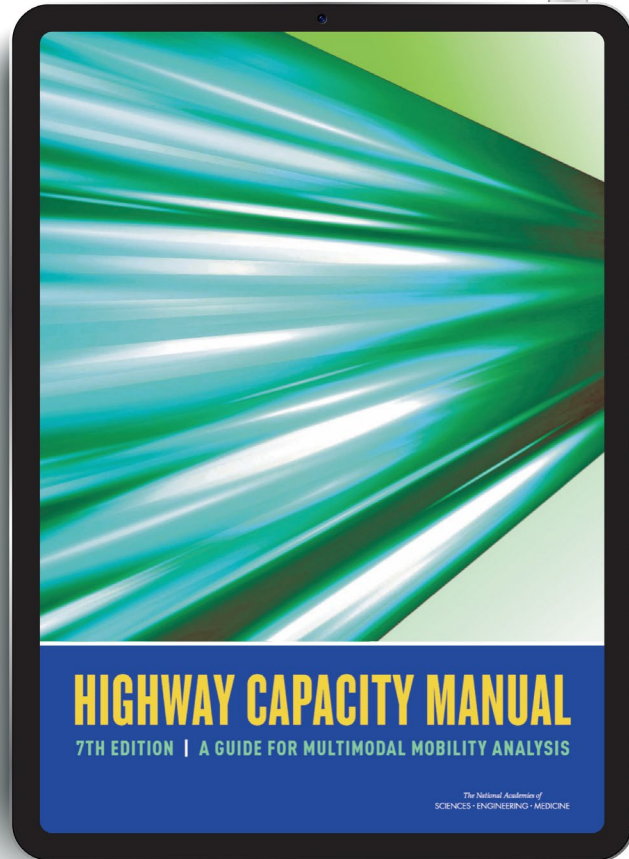
Roundabouts Supplemental

### CHAPTER 26 FREEWAY AND HIGHWAY SEGMENTS: SUPPLEMENTAL

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## Changes in HCM 7



### **Capacity Adjustment Factors (CAFs) for CAVs**

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

### **Service Volume Tables for CAVs**

Given a market penetration rate of CAVs, what hourly and/or daily service volumes are achievable for planning applications?

# CAV Capacity Adjustment – Freeways (Basic Segments)

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

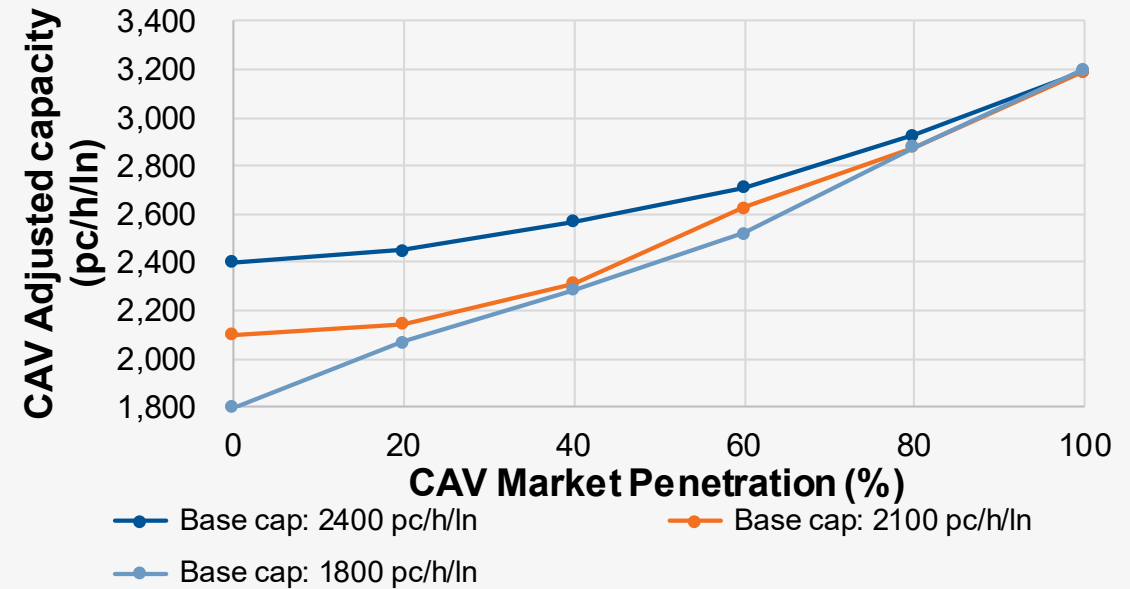
Main user input: % Market Penetration (0 to 100%)

- 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

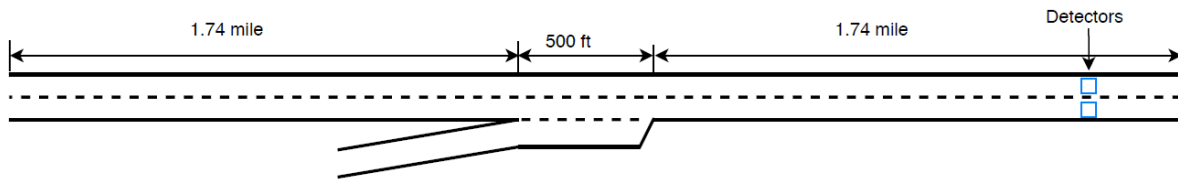


Proportion of CAVs in Traffic Stream	Adjusted Segment Capacity		
	2,400 pc/h/ln	2,100 pc/h/ln	1,800 pc/h/ln
0	1.00	1.00	1.00
20	1.02	1.02	1.15
40	1.07	1.10	1.27
60	1.13	1.25	1.40
80	1.22	1.37	1.60
100	1.33	1.52	1.78

Capacity adjustments – Basic Segments

# CAV Capacity Adjustment – Freeways (Merge Segments)

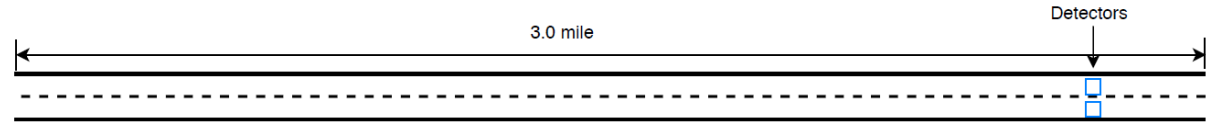
## Merge Segment



(b) Sketch of freeway merge segment with detectors

Proportion of CAVs in Traffic Stream	$CAF_{CAV}$
0	1.00
20	1.02
40	1.07
60	1.16
80	1.33
100	1.45

## Basic Segment

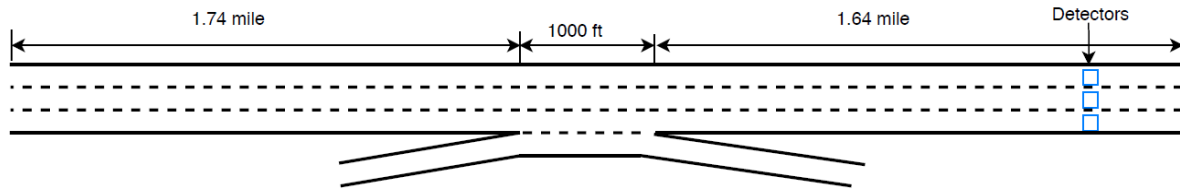


(a) Sketch of basic freeway segment with detectors

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
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80	1.22	1.37	1.60
100	1.33	1.52	1.78

# CAV Capacity Adjustment – Freeways (Weave Segments)

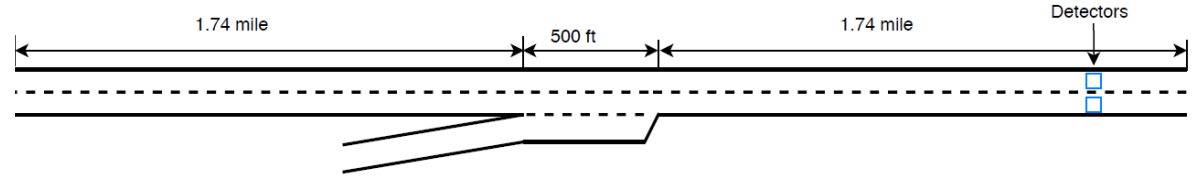
## Weave Segment



(c) Sketch of freeway weaving segment with detectors

Proportion of CAVs in Traffic Stream	Volume Ratio		
	0.2	0.3	0.4
0	1.00	1.00	1.00
20	1.03	1.04	1.05
40	1.08	1.08	1.09
60	1.15	1.15	1.13
80	1.23	1.22	1.20
100	1.37	1.37	1.34

## Merge Segment



(b) Sketch of freeway merge segment with detectors

Proportion of CAVs in Traffic Stream	$CAF_{CAV}$
0	1.00
20	1.02
40	1.07
60	1.16
80	1.33
100	1.45

## CAV Service Volume Tables - Freeways

Area Type	Terrain	Proportion of CAVs in Traffic Stream					
		0%	20%	40%	60%	80%	100%
Urban	Level	19,900	20,500	21,800	24,600	26,800	29,700
Urban	Rolling	19,000	19,900	21,400	24,500	26,800	29,700
Rural	Level	16,800	17,900	19,300	22,000	24,400	26,800
Rural	Rolling	15,200	17,200	19,100	21,600	24,400	26,800

Notes: CAV = connected and automated vehicle, defined here as a vehicle with an operating cooperative adaptive cruise control system.

Values represent the maximum annual average daily traffic per lane at LOS E.

Urban assumptions: Free-flow speed = 70 mph, 5% trucks, PHF = 0.94, *K*-factor = 0.09, *D*-factor = 0.60.

Rural assumptions: Free-flow speed = 70 mph, 12% trucks, PHF = 0.94, *K*-factor = 0.10, *D*-factor = 0.60.

CAV assumptions: Average intervehicle gap within CAV platoons = 0.71 s based on a distribution (see text), CAV interplatoon gap = 2.0 s, maximum CAV platoon size = 10 pc, human-driven vehicles operate with average gaps calibrated to 2,400 pc/h/ln.

### Exhibit 26-18

Daily Maximum Service Volumes for Basic Freeway Segments with CAV Presence (2-way veh/day/ln)

# CAV Capacity Adjustment: Signalized Intersections

## Adjustment to Saturation Flow Rate

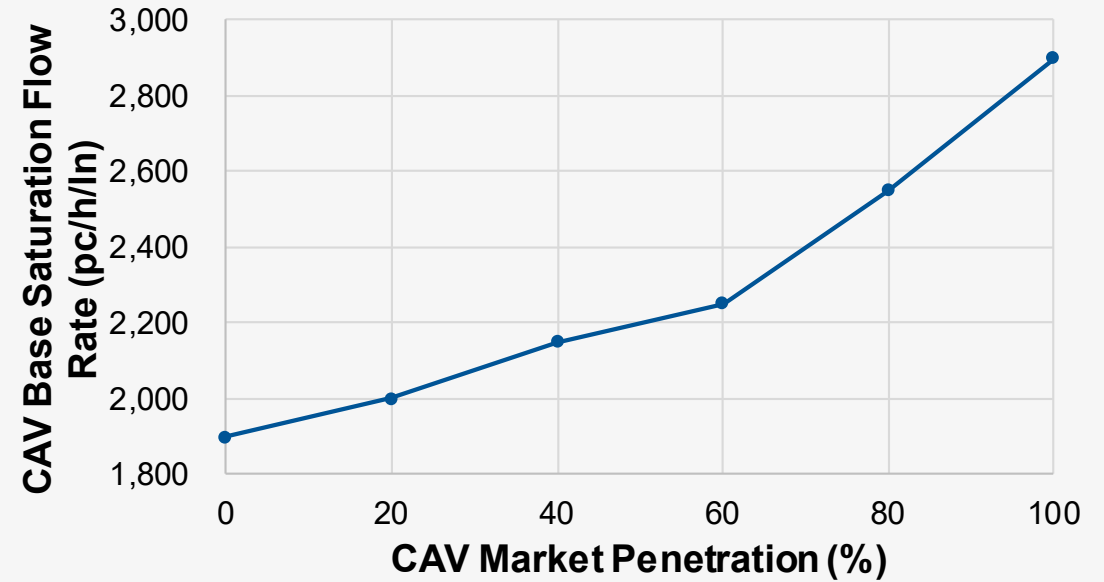
Main user input: % **Market Penetration (0 to 100%)**

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

## Addresses protected and permitted phases

### Does not consider:

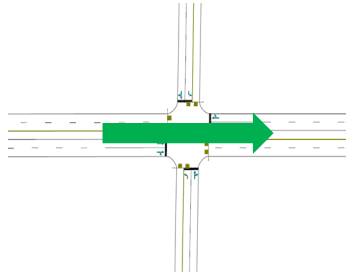
- Interactions with pedestrians and other modes
- Driveways or access points impacting saturation flow rates



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

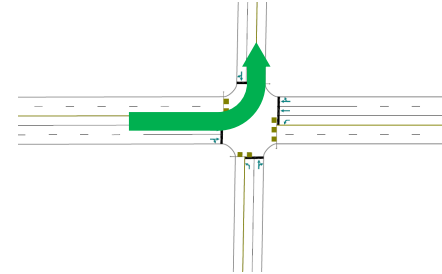
*Saturation Flow Rate adjustments – Through movements*

# CAV Capacity Adjustment – Through Movements and Protected Left Turns



**Through Movements**

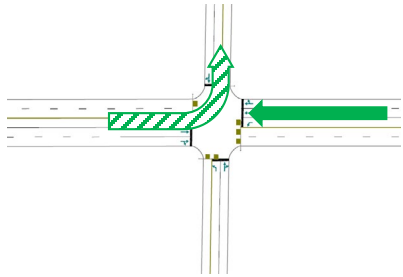
Proportion of CAVs in Traffic Stream	Saturation Flow Rate Adjustment for Through Movements
0	1.00
20	1.05
40	1.13
60	1.18
80	1.34
100	1.53



**Protected Left Turns**

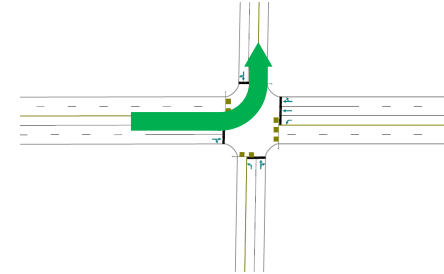
Proportion of CAVs in Traffic Stream	Saturation Flow Rate Adjustment for Protected Left Turns
0	1.00
20	1.01
40	1.07
60	1.11
80	1.21
100	1.56

## CAV Capacity Adjustment – Permitted Left Turns



Permitted Left Turns

Proportion of CAVs in Traffic Stream	Saturation Flow Rate Adjustment for Permitted Left Turns by Opposing Through Volume Per Lane (pc/h/ln)			
	300	450	600	750
0	1.00	1.00	1.00	1.00
20	1.12	1.04	1.03	1.07
40	1.20	1.16	1.12	1.18
60	1.29	1.22	1.26	1.36
80	1.43	1.43	1.57	1.60
100	1.76	1.72	1.66	1.90



Protected Left Turns

Proportion of CAVs in Traffic Stream	Saturation Flow Rate Adjustment for Protected Left Turns
0	1.00
20	1.01
40	1.07
60	1.11
80	1.21
100	1.56

# 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%

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21

## CAV Capacity Adjustment - Roundabouts

### Roundabout Capacity Estimation

$$C_{pce} = Ae^{-B \cdot v_c}$$

$$A = \frac{3,600}{t_f}$$

$$B = \frac{t_c - (t_f/2)}{3,600}$$

where

$C_{pce}$  = lane capacity (pc/h),

$v_c$  = conflicting flow (pc/h),

$t_c$  = critical headway (s), and

$t_f$  = follow-up headway (s).

### Adjustment Factor for CAVs

$$C_{adj} = A_{adj} \cdot e^{-B_{adj} \cdot v_c}$$

$$f_A = A_{adj}/A$$

$$f_B = B_{adj}/B$$

where

$f_A$  = adjustment factor for parameter  $A$ ,

$f_B$  = adjustment factor for parameter  $B$ , and

$C_{adj}$  = adjusted entry capacity (pc/h).

## CAV Capacity Adjustment – Follow-up Headway and Critical Headway under Different Market Penetration Rate

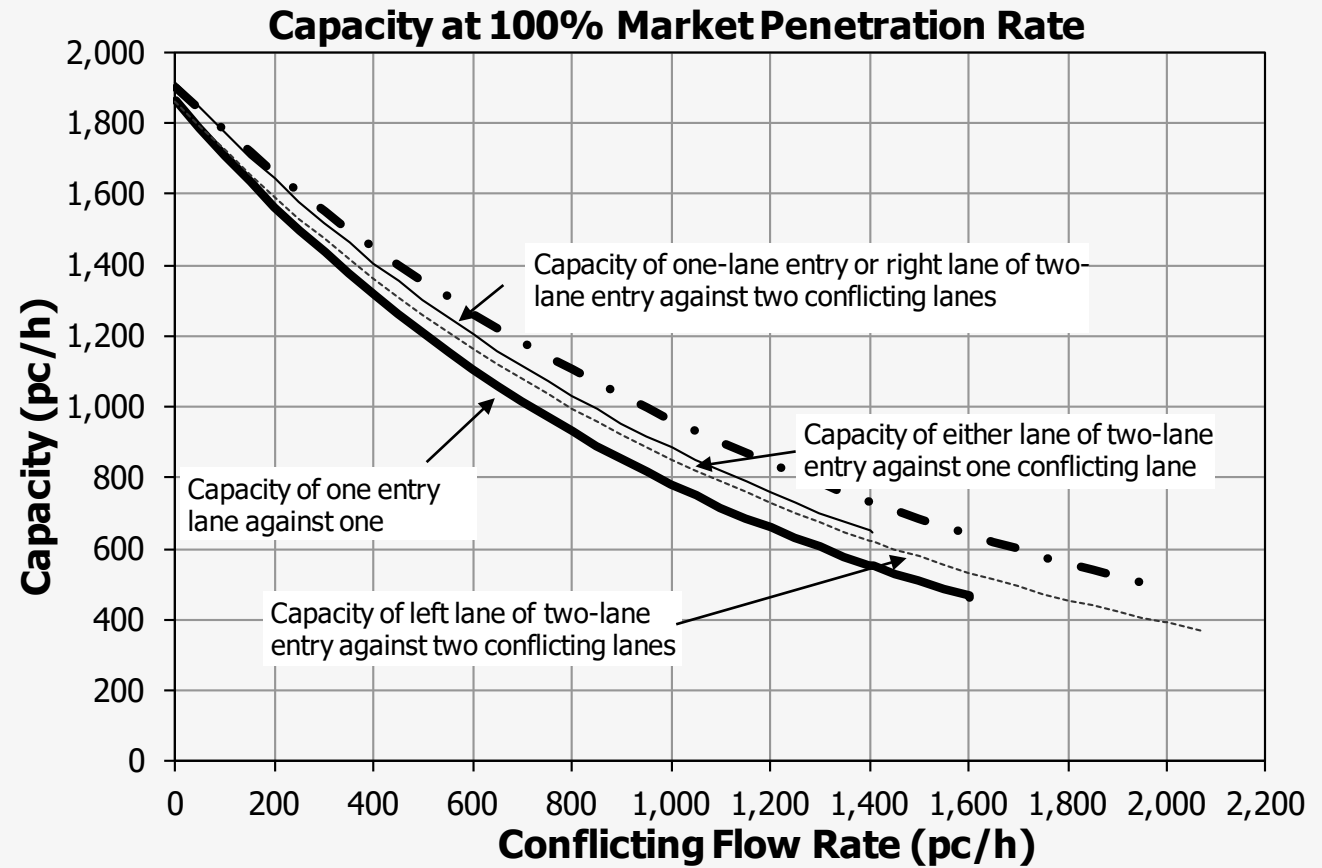
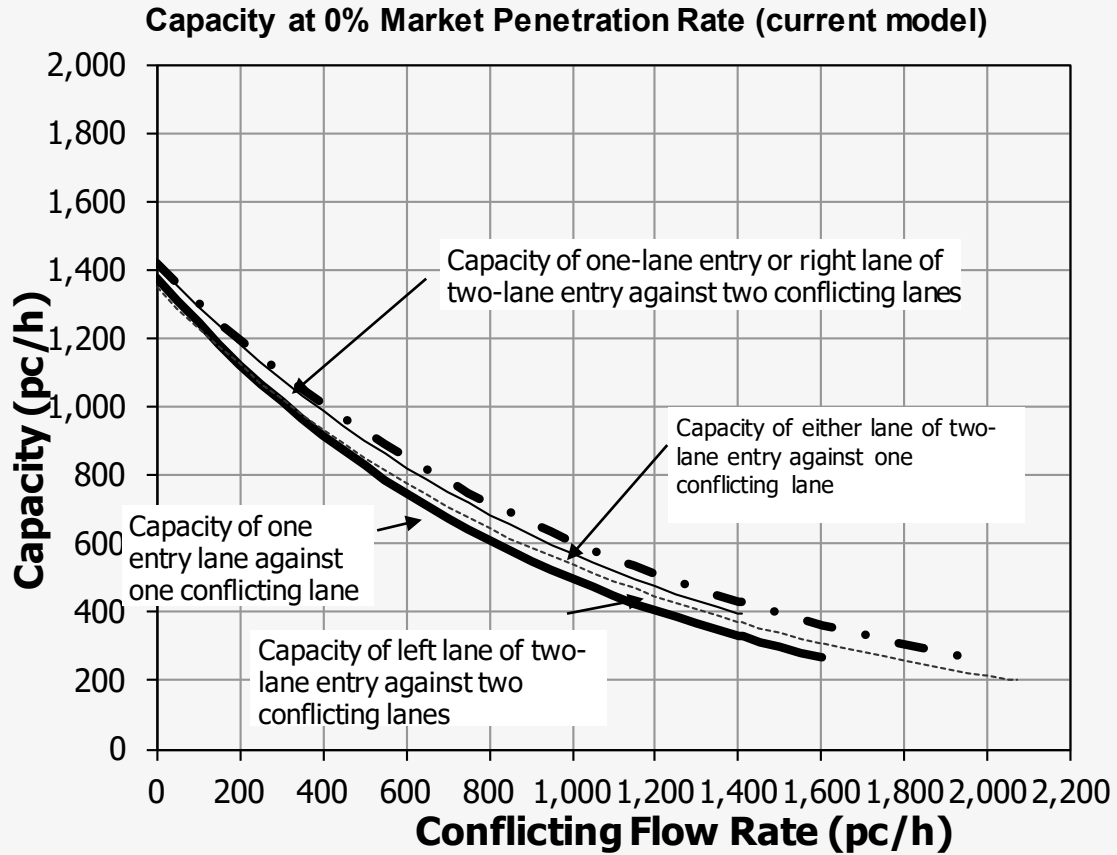
		<u>CAV Market Penetration Rate (MPR)</u>						
		0%	20%	40%	60%	80%	100%	
Follow-Up headway (sec)	Single-Lane	2.62	2.48	2.34	2.21	2.06	1.93	≈ 26%
	Double-Lane, Left	2.60	2.47	2.33	2.19	2.05	1.92	
	Double-Lane, Right	2.54	2.46	2.31	2.15	2.01	1.89	
Critical headway (sec)	Single-Lane	4.08	3.99	3.86	3.73	3.60	3.48	≈ 15%
	Double-Lane, Left	4.02	3.91	3.79	3.67	3.55	3.44	
	Double-Lane, Right	3.93	3.83	3.71	3.60	3.49	3.39	

## CAV Capacity Adjustment - Roundabouts

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

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



## Summary

- Effects of connected and automated vehicles (CAVs) were incorporated into the HCM using an “agent-based” simulation approach
- **Capacity adjustment factors (CAFs)** and **service volume tables** were developed under varying market penetration rate (MPR) for:
  - Freeway segments
  - Signalized intersections
  - Roundabouts
- Capacity increases were found to be less substantial when MPR <40%
- CAFs were developed in the form of lookup tables for quick evaluation and planning level applications

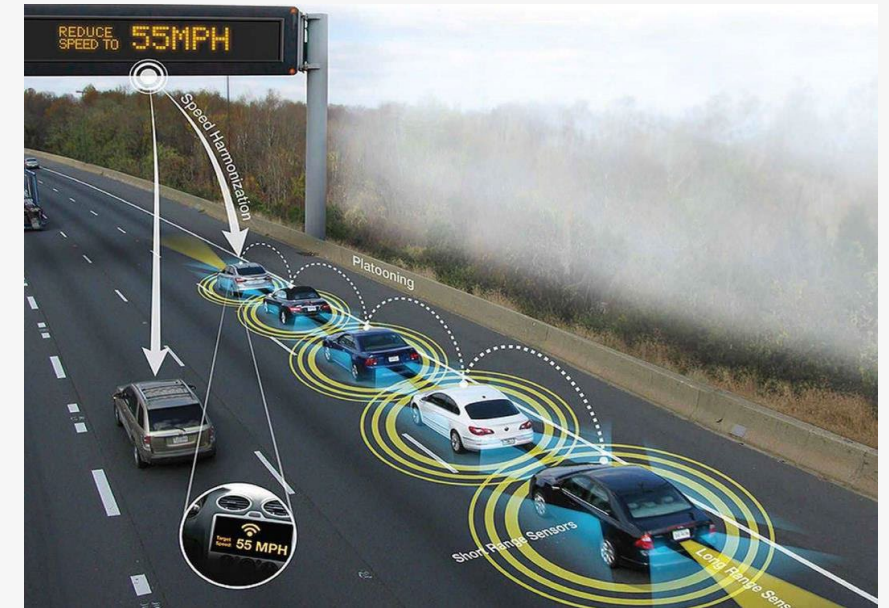
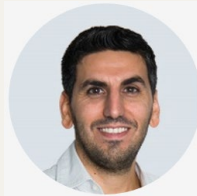


Image Credit: PCQuest

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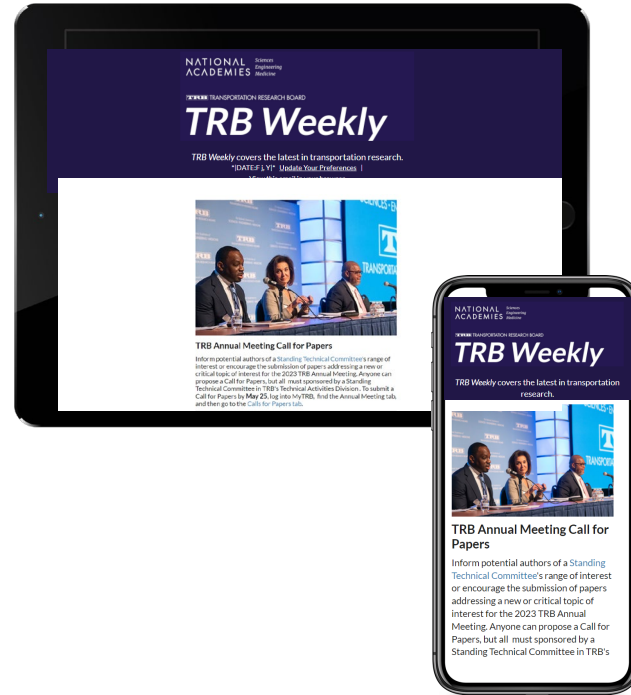


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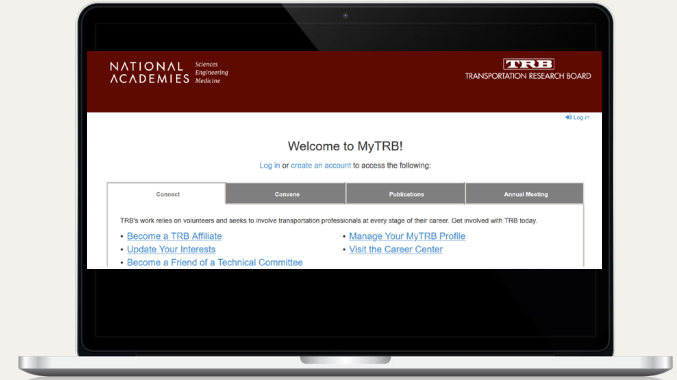
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