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Think Forward

Highway Capacity Manual and Capacities in the SCAG Model

presented to

Caltrans District 7

presented by

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Agenda

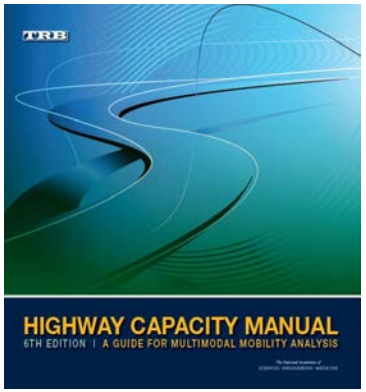
- Highway Capacity Manual (HCM)
- Introductions of capacities in the SCAG Model
- Comparisons of capacities from HCM and the SCAG Model
- How to change capacities in SCAG model

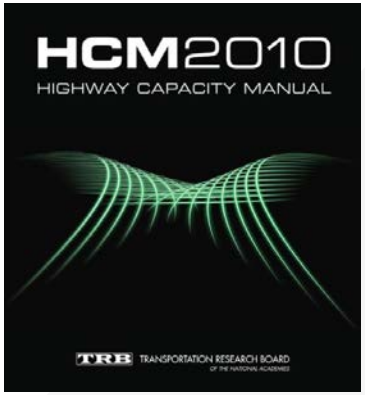
Highway Capacity Manual (HCM)

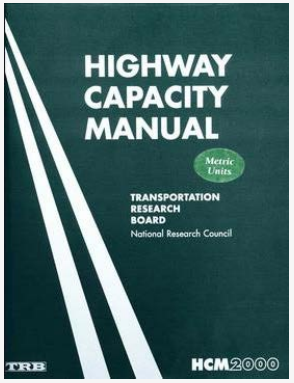
- The Highway Capacity Manual (HCM) is a publication of the Transportation Research Board (TRB) of the National Academies of Science in the United States.
- It contains concepts, guidelines, and computational procedures for computing the capacity and quality of service of various highway facilities, and the effects of mass transit, pedestrians, and bicycles on the performance of these systems.

HCM Versions

HCM 1950 → HCM 1965 → HCM 1985 → HCM 2000 → HCM 2010 → HCM 2016







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HCM Objectives

- Define performance measures and describe survey methods for key traffic characteristics
- Provide methodologies for estimating and predicting performance measures
- Explain methodologies at a level of detail that allows readers to understand the factors affecting multimodal operation

HCM Intended Use

- Levels of analysis: operations, design, preliminary engineering, and planning
- Travel modes: motorized vehicles, pedestrian, and bicycle, plus transit when it is part of a multimodal urban street facility.
- Spatial coverage: points, segments, and facilities
- Temporal coverage: undersaturated (free-flow) and oversaturated (congested) conditions

HCM 2016 Volumes

Concepts	• Traffic operations and capacity concepts • Quality and level-of-service concepts
Uninterrupted Flow	• Freeway and multilane highway segments • Freeway weaving segments • Freeway merge and diverge segments • Two-lane highways
Interrupted Flow	• Urban street segments • Signalized intersections • Two-way Stop-controlled (TWSC) and AWSC Intersections • Roundabouts

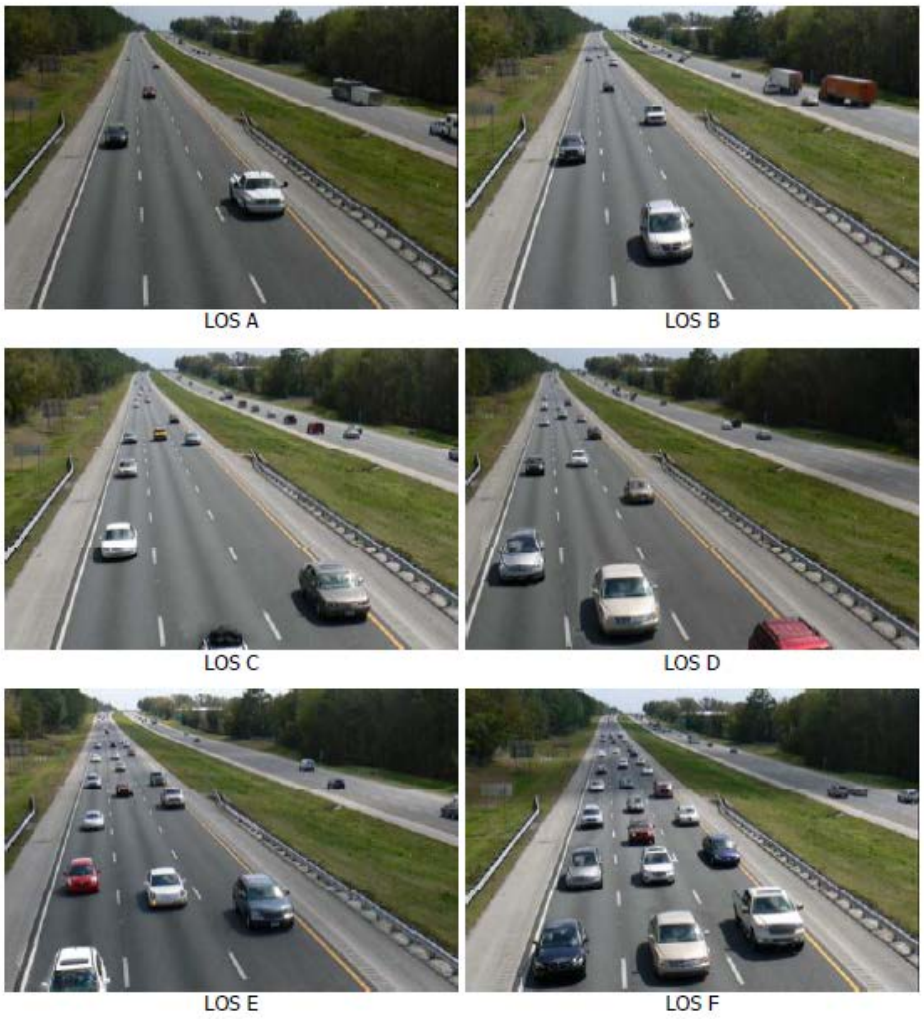
HCM Basic Concepts

- Capacity
  - The maximum number of vehicles that can pass a given point during a specified period under the prevailing traffic condition
  - It is the maximum flow
  - The normal unit is Vehicles per Hour (v/h) or Passenger Cars per Hour (pc/h)
  - Capacities for different level of services

HCM Basic Concepts

- Level of Service (LOS)
  - A quantitative stratification of a performance measure or measures that represent quality of service
  - Measured on an A-F scale, with LOS A representing the best operating conditions and LOS F the worst.

Level of Service



A: free flow

B: reasonably free flow

C: stable flow

D: approaching unstable flow

E: unstable flow

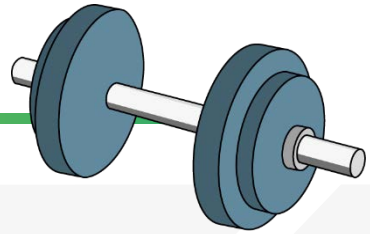
F: breakdown flow

HCM Basic Concepts

- The capacities in HCM are in PCEs.
- Passenger Car Equivalent (PCE):
  - A Passenger Car Equivalent is essentially the impact that a mode of transport has on traffic variables (such as headway, speed, density) compared to a single car.
- PCEs in the SCAG Model:

Vehicles	PCEs
Autos	1.0
Light Truck	1.2
Medium Truck	1.5
Heavy Truck	2.0

HCM Basic Concepts



Exercise

- The traffic counts on a roadway is as follows.
- What are the traffic counts in PCEs?

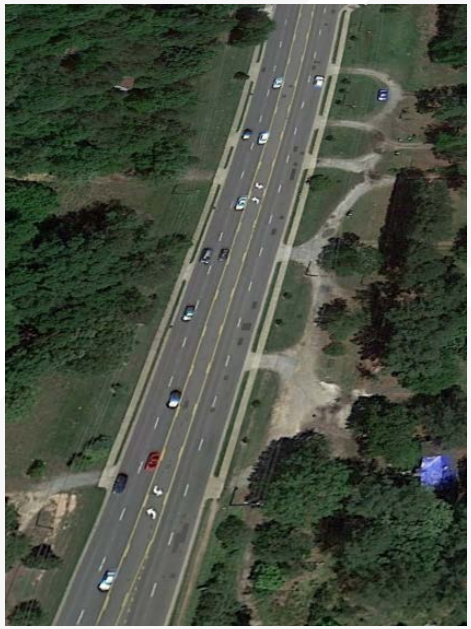
Vehicles	PCEs	Number of Vehicles	Number of Vehicles in PCEs
Autos	1.0	100	
Light Truck	1.2	20	
Medium Truck	1.5	10	
Heavy Truck	2.0	5	
Total	NA	135	

Freeways and Multilane Highways

- HCM 2016 Chapter 12
- They are outside the influence area of any merge, diverge, or weaving segments and of any signalized intersections.
- Difference between freeways and multilane highways:
  - No driveways or cross-street access on freeways

Freeways and Multilane Highways

- Rule of thumb: intersection spacing > 2 miles for multilane highways



Freeways and Multilane Highways Capacities

Free Flow Speed (mil/h)	Capacity of Basic Freeway Segments (pc/h/ln)	Capacity of Multilane Highway Segments (pc/h/ln)
75	2,400	NA
70	2,400	2,300
65	2,350	2,300
60	2,300	2,200
55	2,250	2,100
50	NA	2,000
45	NA	1,900

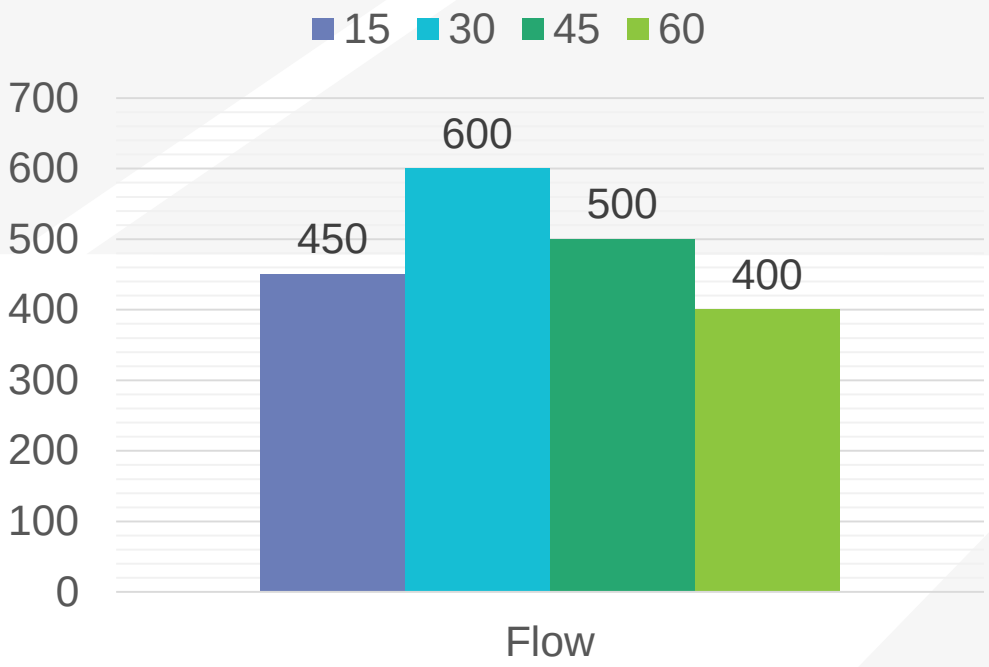
Notes: 1. These base capacities reflect ideal conditions on a facility without any capacity-reducing effects.
2. These capacities apply to a peak 15-min period (expressed as hourly flow rates)

Freeways and Multilane Highways

- Ideal conditions without any capacity-reducing effects for freeways and multilane highways
  - No heavy vehicles
  - No grades
  - No additional friction effects due to poor pavement conditions, narrow lanes or lighting conditions

Freeways and Multilane Highways

- Flow rate over 15-min period vs. 1-h period



- Flow Rate over the peak 15-min:
  - 600 * 4 = 2,400
- Flow Rate over the one hour period:
  - 400 + 600 + 500 + 400 = 1,950
- Peak Hour Factor (PHF) = 1950/2400 = 0.8125
- Typical PHFs range from 0.80 to 0.95

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Two-lane Highways

- HCM 2016 Chapter 15
- A roadway that generally has a two-lane cross section, one lane for each direction of flow, although passing and climbing lanes may be provided periodically.
- Why separate multilane and two-lane highways – different characteristics:
  - For two-lane highways, passing maneuvers must be made in the opposing lane
  - For two-lane highways, fast-moving vehicles sometimes are blocked by slow-moving vehicles.

Two-lane Highways

- Considered as an uninterrupted facility (intersection spacing > 2 miles)

Two-lane Highways

- A two-lane highway's capacity under base conditions is 1,700 pc/h in one direction, with a limit of 3,200 pc/h for the total of both directions.
- Base conditions are ideal conditions and rarely observed:
  - Lane widths >= 12 feet
  - Shoulder widths >= 6 feet
  - No no-passing zones
  - All are passenger cars (no trucks)
  - Level terrain
  - No impediments to through traffic etc.

Urban Streets

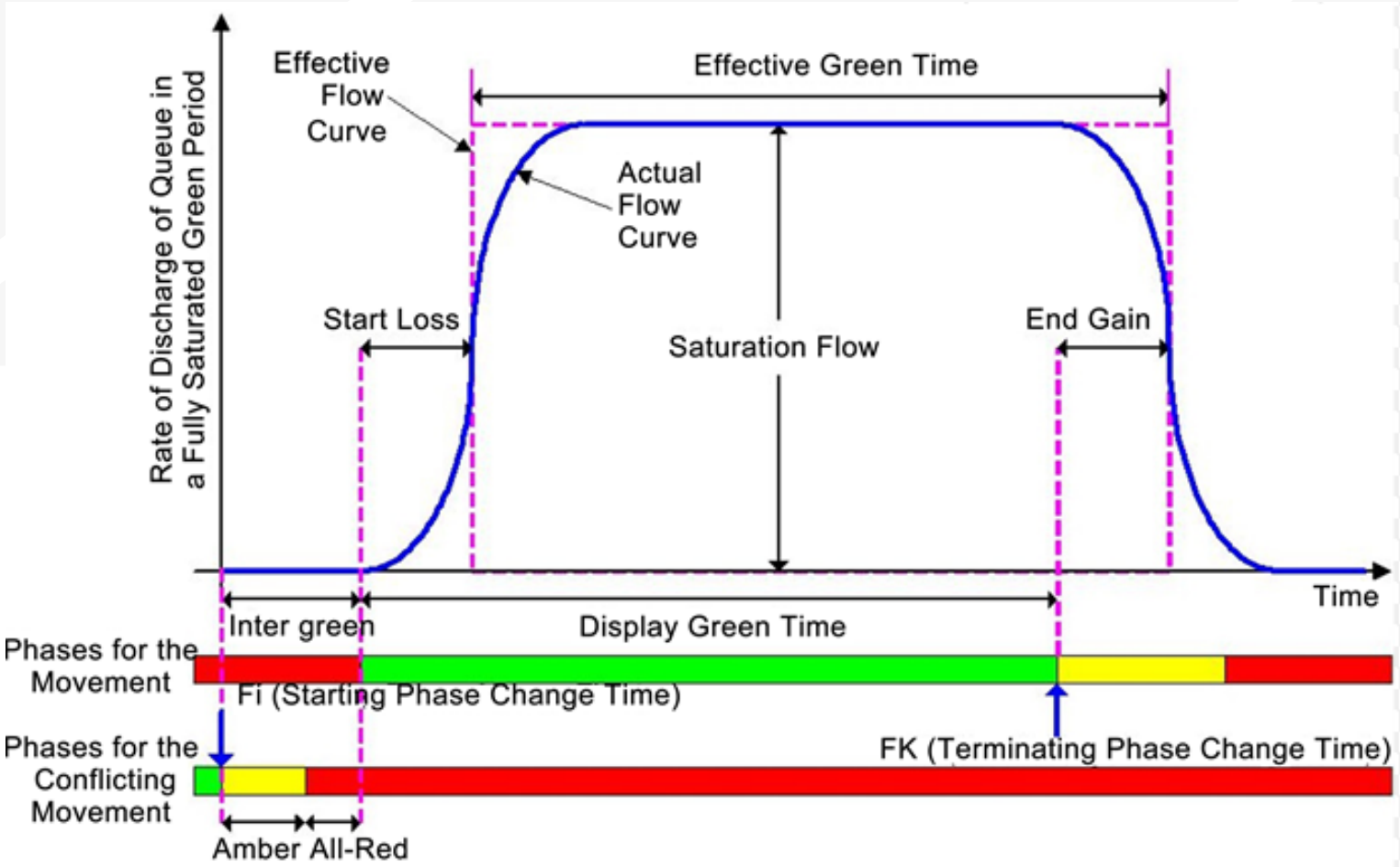
- HCM 2016 Chapter 18
- An urban street is a street with a relatively high density of driveway and cross-street access, with traffic signals or interrupting STOP or YIELD signs no farther than 2 mil apart.
- The capacity of an urban street segment is determined by the capacity at the intersections:
  - Signalized Intersections
  - Two-way Stop-controlled (TWSC) Intersections
  - All-way Stop-controlled (AWSC) Intersections
  - Roundabouts

Signalized Intersections

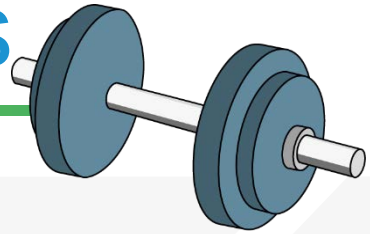
- HCM 2016 Chapter 19
- Capacity is computed as the product of adjusted saturation flow rate and effective green-to-cycle length ratio.
  - $S = s_0 f_w f_{HVg} f_p f_{bb} f_a f_{LU} f_{LT} f_{RT} f_{Lpb} f_{Rpb} f_{wz} f_{ms} f_{sp}$
  - s_0 is the base saturation flow rate (pc/h/ln)
  - The default value for s_0 is
    - Metro pop > 250,000: 1,900 pc/h/ln
    - Otherwise: 1,750 pc/h/ln
  - The adjustment factors are adjustments for lane width, parking, bus blocking, heavy vehicle, left turn traffic percentage etc.

Signalized Intersections

- Effective green time



Capacities for Urban Streets



Exercise

- An urban street has a base saturation flow rate of 1,900 pc/h/ln
- Assume the product of all adjustment factors is 0.90
- The effective green time for the downstream intersection is 60 seconds
- The signal cycle length for the downstream intersection is 110 seconds
- What is the capacity for this urban street?
- Adjusted saturation flow rate: $1900 * 0.9 =$
- Effective green-to-cycle ratio: $\frac{60}{110} = 0.545$
- Capacity: $1710 * 0.545 = 933$ pc/h/ln

Software for HCM

- Highway Capacity Software 7 (HCS7)
- Updated to be compatible with HCM 2016

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HCM Summary

Facility types	Capacity Range	Factors
Freeways and multilane highways	1,900 ~ 2,400 pc/h/ln *	Free-flow speeds
Two-lane highways	1,700 pc/h/ln in one direction, with a limit of 3,200 pc/h/ln for both directions *	
Urban street	= 1,900 × factors × effective green-to-cycle length ratio	Effective green-to-cycle length ratio, lane width, parking etc.

* For the deal conditions

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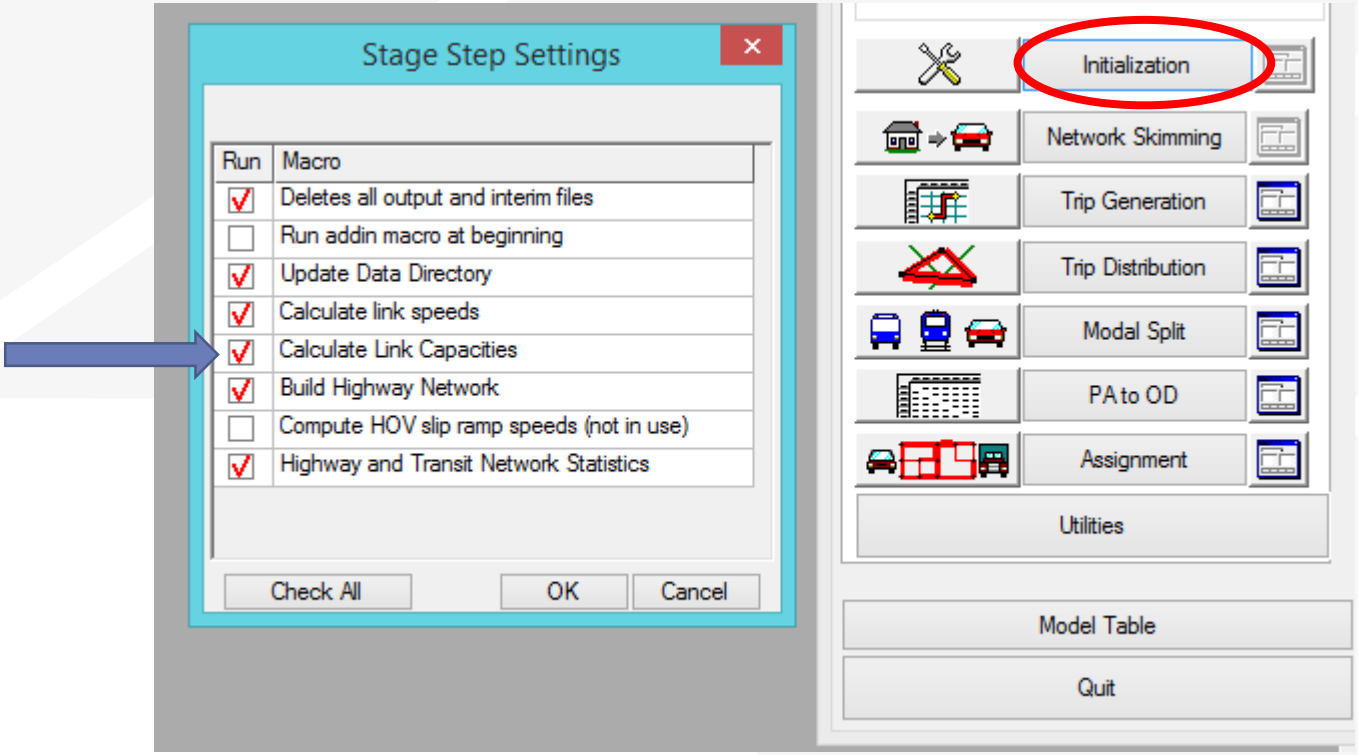
Capacity Calculation in SCAG



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Capacity Calculation in SCAG

- Input
  - Output highway network
    - networks\Outputs\scag_network_working.dbd
  - Capacity lookup table
    - networks\Inputs\cap_complex.bin

Capacity for Arterials

- Facility Type for Arterials
  - >= 30 and <= 79
    - 3 - Expressway/Parkway
    - 4 - Principal Arterial
    - 5 - Minor Arterial
    - 6 – Major Collector
    - 7 - Minor Collector
  - NOT applied to
    - 1 - Freeways
    - 2 - HOV
    - 8 - Ramps
    - 9 – Trucks
    - 100 - Centroid connector - Tier 1
    - 200 - Centroid connector - Tier 2

Capacity for Arterials

- Factors
  - Facility Type
  - Area Type
  - Number of lanes
  - Number of lanes for the crossing link
    - Angle of the crossing link
  - Parking
  - One-way
  - Divided or not

Capacity for Arterials

Table 4-3: Year 2008 Arterial / Expressway Capacity (Signal Spacing <2 miles)

On\Crossing	2-Lane	4-Lane	6-Lane	8-Lane
	-- AT1_Core --			
2-Lane	475	425	375	375
4-Lane	650	600	500	500
6-Lane	825	700	600	550
8-Lane	825	700	650	600
	-- AT2_Central Business District --			
2-Lane	575	525	475	475
4-Lane	725	675	550	550
6-Lane	875	750	650	600
8-Lane	875	750	700	650
	-- AT3_Urban Business District --			
2-Lane	600	525	475	475
4-Lane	750	675	575	575
6-Lane	900	775	675	625
8-Lane	900	775	725	675
	-- AT4_Urban --			
2-Lane	625	550	500	500
4-Lane	800	725	600	600
6-Lane	950	825	700	650
8-Lane	950	825	775	700
	-- AT5_Suburban --			
2-Lane	675	600	525	525
4-Lane	825	750	625	625
6-Lane	975	850	750	675
8-Lane	975	850	800	750
	-- AT6_Rural --			
2-Lane	675	600	525	525
4-Lane	825	750	625	625
6-Lane	975	850	750	675
8-Lane	975	850	800	750
	-- AT7_Mountain --			
2-Lane	575	500	425	425
4-Lane	750	675	550	550
6-Lane	925	800	700	625
8-Lane	925	800	750	700

Notes: Capacities are in passenger car per lane per hour (pcplph).
Lanes are mid-block 2-way lanes.
Add 20% for one-way streets.
Add 5% for divided streets.

- This table is in the SCAG's documentation.
- This table does not list all factors that affect capacities for arterials, such as
  - Facility Type
  - Parking (add 10% for AM, PM and MD capacities on streets that allow parking for EV and NT, but do not allow parking for AM, PM and MD)

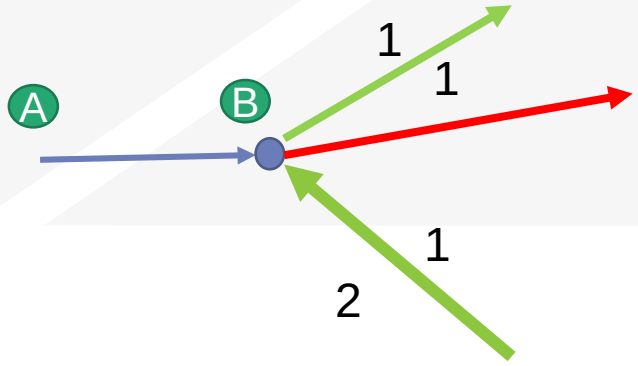
Capacity for Arterials

- Unit for capacities
  - Pcplph
    - Passenger car per lane per hour
- They are level of service (LOS) E capacities

Number of lanes on crossing links

- Determine crossing links
  - Calculate the angle between the studied link and all joining links
  - Joining links that meet the following conditions are regarded as crossing links:
    - The angle should be >= 30 and <= 150
    - The crossing links should be arterials
  - Calculate the average number of lanes for all crossing links
    - avg_cross_lanes = Floor(sum of all cross lanes / number of links + 0.5)

Number of lanes on crossing links



In this example

- the red link is not a crossing link
- the two green links are crossing links
- Floor ((3 + 2) / 2 + 0.5) = 3

Lookup table

- Capacity lookup table: networks\Inputs\cap_complex.bin
- Fields are
  - Facility Type
  - Area Type
  - Crossing Lanes
  - On Lanes
  - Capacity per lane per hour (pcplph)
- There are 1,564 records

Lookup table

- The capacities on ALL links are looked up based on the lookup table, but some of the capacities are replaced by other values in later steps, such as:
  - Highways
  - Freeways and HOVs
  - On-ramps

Lookup table

FACILITY_TYPE	AREA_TYPE	CROSSING_LANES	ON_LANES	R_CAPACITY
50	4	0	99	575
50	4	2	2	650
50	4	2	4	800
50	4	2	6	950
50	4	2	99	950
50	4	4	2	600
50	4	4	4	725
50	4	4	6	825
50	4	4	99	825
50	4	6	2	575
50	4	6	4	625
50	4	6	6	700
50	4	6	99	775
50	4	99	2	550
50	4	99	4	600
50	4	99	6	650
50	4	99	99	700

All records with Facility Type = 50 and Area Type = 4

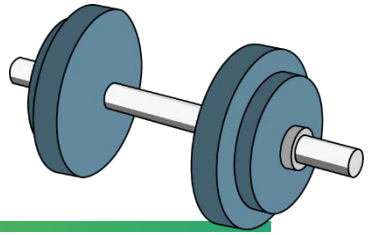
How to read a lookup table in TransCAD

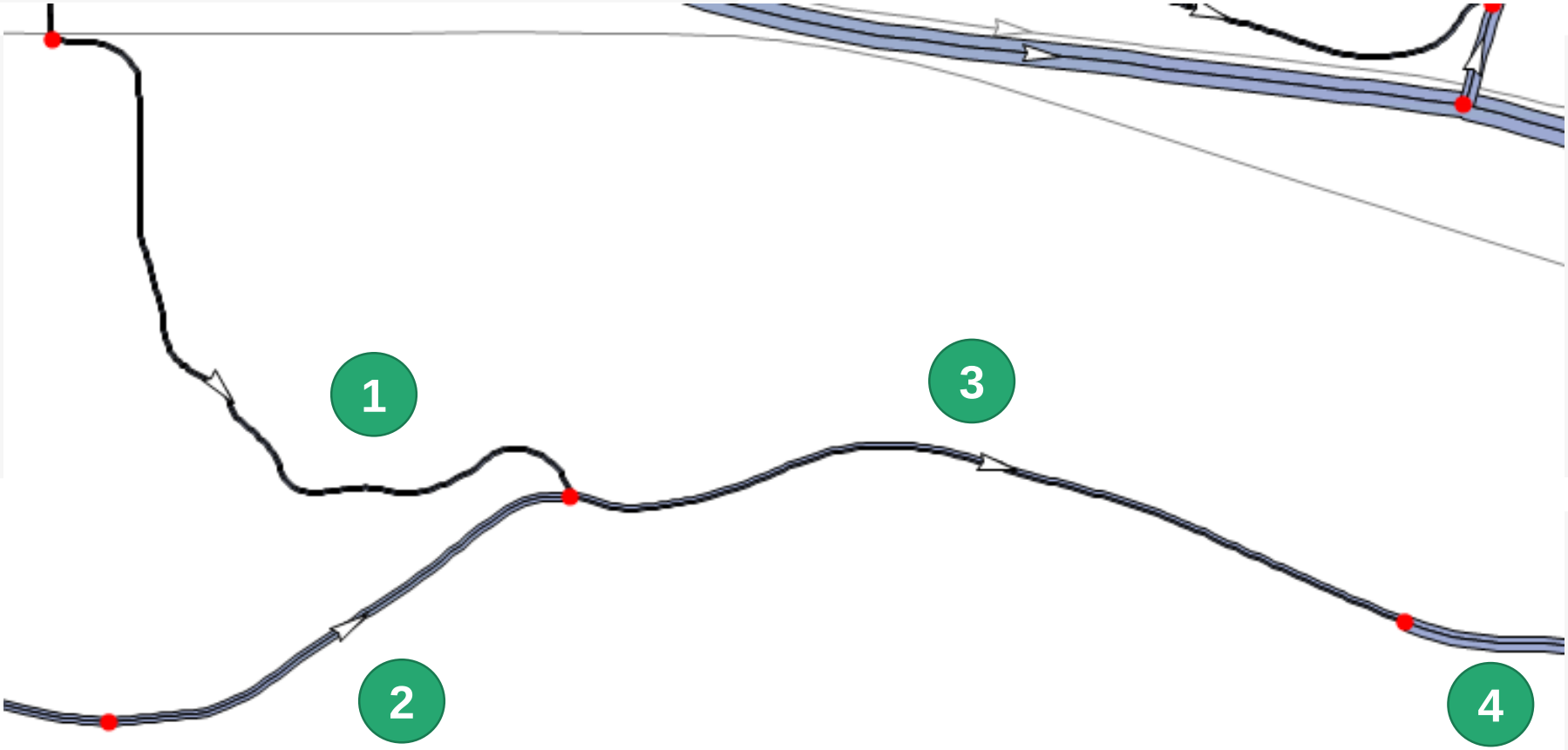
Each field defines the upper bound of the range, for example, since the second record has ON_LNAES = 2, a record with 50, 4, 2 and 1 will return the capacity value of 650 as well.

FACILITY_TYPE	AREA_TYPE	CROSSING_LANES	ON_LANES	R_CAPACITY
50	4	0	99	575
50	4	2	2	650
50	4	2	4	800
50	4	2	6	950
50	4	2	99	950
50	4	4	2	600
50	4	4	4	725
50	4	4	6	825
50	4	4	99	825
50	4	6	2	575
50	4	6	4	625
50	4	6	6	700
50	4	6	99	775
50	4	99	2	550
50	4	99	4	600
50	4	99	6	650
50	4	99	99	700

Returned value based on the lookup values

Arterial Capacity - Exercise





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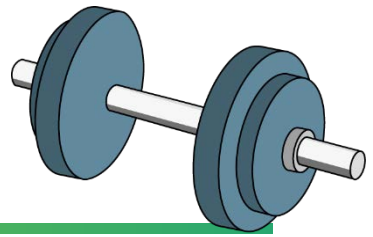
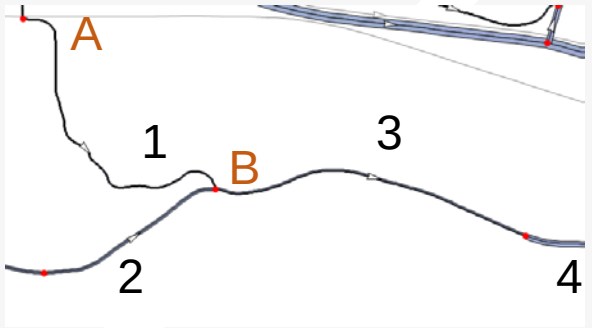
Arterial Capacity - Exercise



	1	2	3	4
ID	2760311	2760309	2760312	2760313
Length	0.77	0.46	0.77	0.58
Dir	0	0	0	0
AB_Facility_Type	60	50	50	51
BA_Facility_Type	60	50	50	51
AB_AMLANES	1	1	1	2
BA_AMLANES	1	1	1	2
FWY_Main_Lane	--	--	--	--
FWY_Aux_Lane	--	--	--	--
FWY_Acc_Dec_Lane	--	--	--	--
AB_AreaType	4	4	4	4
BA_AreaType	4	4	4	4
MODE	2	2	2	2
AB_PostedSpeed	30	30	30	40
BA_PostedSpeed	30	30	30	40
AB_AMPARK	--	--	--	--
BA_AMPARK	--	--	--	--
Capacity_Multiplier	1.00	1.00	1.00	1.00
AB_CROSSLANES				
BA_CROSSLANES				
AB_HRCAPACITYAM				
BA_HRCAPACITYAM				
[AB CAPA AM]				
[BA CAPA AM]				



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Adjustment to Arterial Capacities

	Adjustment	Applied to
One-Way	+ 20%	One-way links (Facility type >=30 and < 80)
Divided Street	+ 5%	Divided street (Facility type = 31, 41, 51, 61, 71, 32, 42, 52, 62 or 72)
Smart Street	+ 10%	AM, PM and MD only, for links that allows on-street parking during NT and EVE, but does not allow on-street parking during AM, PM or MD (with [AB/BA]_[Period]PARK = 1)

Notes: the factors are applied to all lanes

Capacity for Highways (Signal Spacing >= 2 Miles)

- Applied to facilities with
  - Facility type >= 30 and <= 79 (the same as the arterials) and
  - Length > 2
- Issues
  - If a link is split, the capacity on a link could drop dramatically.

Capacity for Highways (Signal Spacing >= 2 Miles)

- Capacities for highways are only determined by facility type (multi-lane or 2-lane), and posted speed

Table 4-4: Year 2008 Arterial / Expressway Capacity (Signal Spacing >=2 Miles)

Type	Posted Speed	Capacity (Per Lane)
Multi-Lane Highway	45	1,600
	50	1,700
	55	1,800
	60	1,900
2-Lane Highway	--	1,400

Capacity for Freeways and HOVs

- Facility Type for Freeways
  - >= 10 and <= 21, including
    - 10 - Freeway
    - 20 - HOV 2
    - 21 - HOV 3+
  - Does not include facility type = 22 (HOV – HOV Connector)

Capacity for Freeways and HOVs

- Factors
  - Posted Speed
  - Lane type
    - Auxiliary lane has fixed capacity of 1,000 per lane
    - Acceleration/Deceleration lane has no capacity

Table 4-5: Year 2008 Freeway Capacity

Type	Posted Speed (mile per hour)	Capacity (passenger car per lane per hour)
Freeway/HOV	55 and below	1,900
	60 and 65	2,000
	70 and above	2,100
Auxiliary Lane	--	1,000

Notes: [AB/BA]_[Period]LANES (such as AB_AMLANES) include Main_Lane, Aux_Lane and Acc_Dec_Lane.

Capacity for On Ramps

- Applied to facilities with
  - Facility type = 82 (Arterial to freeway)
- Factors
  - Area types
  - Lane types (first lane or additional lanes)

Capacity for On Ramps

Table 4-6: Year 2008 Ramp Capacity

	AT1	AT2	AT3	AT4	AT5	AT6	AT7
On-Ramp (first lane)	720	720	720	720	1,400	1,400	1,400
On-Ramp (additional lane)	480	480	480	480	600	1,400	1,400
On-Ramp (off-peak)	1,300	1,300	1,300	1,300	1,400	1,400	1,400

Notes: Use arterial/expressway capacity estimation procedure for off-ramps.
AT1: Core
AT2: Central Business District
AT3: Urban Business District
AT4: Urban
AT5: Suburban
AT6: Rural
AT7: Mountain

Different from this table:

- The off-peak on-ramp capacities are not applied in the model

Capacity for freeway to freeway Ramps

- Applied to facilities with
  - Facility type = 80 (Freeway to Freeway Connector)
  - Facility type = 22 (HOV – HOV Connector)

- Factors
  - Area Type
  - Number of lanes
  - Time period

Capacity for freeway to freeway Ramps

Table 4-5: Year 2008 Freeway Capacity

Type	Posted Speed (mile per hour)	Capacity (passenger car per lane per hour)
Freeway/HOV	55 and below	1,900
	60 and 65	2,000
	70 and above	2,100
Freeway-Freeway Connector	40 and below	1,400
	45	1,600
	50	1,700
	55	1,800
	60 and above	1,900
Auxiliary Lane	--	1,000

Different from this table:

- The capacity for Freeway-Freeway Connector with posted speed of 45 mph is changed to 1,400 in the SCAG model.

Capacity for Other Facility Types

- Based on the lookup table “cap_complex.bin”

Code	Facility Type	Capacity	Notes
81	Freeway to arterial (off-ramp)	375 to 975	Treated in the same way as the arterials
83	Ramp distributor	1000	
84	Ramp from arterial to HOV	1300 for area type 1 – 4 and 1400 for the rest	
85	Ramp from HOV to arterial	375 to 975	Treated in the same way as the arterials
86	Collector distributor	1400	
87	Shared HOV ramps to MF		No records
89	Truck only	720 for area type 1-4 and 1400 for the rest	

Capacity for Other Facility Types

- Based on the lookup table “cap_complex.bin”

Code	Facility Type	Capacity	Notes
90	Truck only	2000	
100	Tier 1 centroid connectors	99999	
200	Tier 2 centroid connectors	99999	

Adjustments Applied to All Capacities

- Field “Capacity_Multiplier”
  - Null and zero values are treated as 1
  - Each link has a “Capacity_Multiplier”
  - It can be used to manually adjust capacities on any links

Convert Hourly Capacity to Period Capacity

	Hourly Capacity Fields	Period Capacity Fields	Factor
AM	[AB/BA]_HRCAPACITYAM	[AB/BA] CAPA AM	3
PM	[AB/BA]_HRCAPACITYPM	[AB/BA] CAPA PM	4
MD	[AB/BA]_HRCAPACITYMD	[AB/BA] CAPA MD	6
EV	[AB/BA]_HRCAPACITYEVE	[AB/BA] CAPA EVE	2
NT	[AB/BA]_HRCAPACITYNT	[AB/BA] CAPA NT	8

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Freeway

The SCAG model uses posted speeds to look up capacity, and HCM uses free flow speeds. To make them comparable, it has been assumed that
free flow speed = posted speed + 5 mph

Free Flow Speed (mil/h)	Capacity in HCM (pc/h/ln)	Capacity in SCAG* (pc/h/ln)	Diff	% Diff
75	2,400	2,100	-300	-13%
70	2,400	2,000	-400	-17%
65	2,350	2,000	-350	-15%
60	2,300	1,900	-400	-17%
55	2,250	1,900	-350	-16%

- SCAG capacities seem low compared to HCM capacities, however
  - The HCM capacities reflect ideal conditions
  - The HCM capacities are expressed as maximum 15-min flow rate within peak hour, and the typical PHF is 0.8-0.95
- So compared to HCM capacities, SCAG freeway capacities are in a reasonable range

Multilane Highway

The SCAG model uses posted speeds to look up capacity, and HCM uses free flow speeds. To make them comparable, it has been assumed that
free flow speed = posted speed + 5 mph

Free Flow Speed (mil/h)	Capacity in HCM (pc/h/ln)	Capacity in SCAG* (pc/h/ln)	Diff	% Diff
65 and above	2,300	1,900	-400	-17%
60	2,200	1,800	-400	-18%
55	2,100	1,700	-400	-19%
50	2,000	1,600	-400	-20%
45	1,900			

- SCAG capacities seem low compared to HCM capacities, however
  - The HCM capacities reflect ideal conditions
  - The HCM capacities are expressed as maximum 15-min flow rate within peak hour, and the typical PHF is 0.8-0.95
- So compared to HCM capacities, SCAG freeway capacities are in a reasonable range

Two-lane Highway

Free Flow Speed (mil/h)	Capacity in HCM (pc/h/ln)	Capacity in SCAG* (pc/h/ln)	Diff	% Diff
All	1,600	1,400	-200	-13%

- SCAG capacities seem low compared to HCM capacities, however
  - The HCM capacities reflect ideal conditions

Arterials

- HCM Capacity
  - 1,900 × factors × effective green-to-cycle length ratio
- SCAG Capacity
  - Capacity range in the table 375 ~ 925 pc/h/ln
  - Add 20% for one-way streets and 5% for divided streets
  - So the capacity range is 375 to 1166 (=925 * 1.2 * 1.05)
  - The equivalent “factors × effective green-to-cycle length ratio” is 0.20 to 0.61, which is in a reasonable range.

Comparison Summary

- Compared to HCM capacities, SCAG capacities are in a reasonable range
- However, further investigations might be needed for specific roadway links

Agenda

- Highway Capacity Manual (HCM)
- Introductions of capacities in the SCAG Model
- Comparisons of capacities from HCM and the SCAG Model
- How to change capacities in SCAG model

Change Capacities in SCAG Model

- To apply region wide changes
  - Change the capacity lookup table networks\Inputs\cap_complex.bin
- To change capacity on specific links
  - Change the field “Capacity_Multiplier” in the input highway network