Detailed Intersection Modelling
Based on Analysis of the Interaction of
Conflicting Traffic Movements

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AECOM

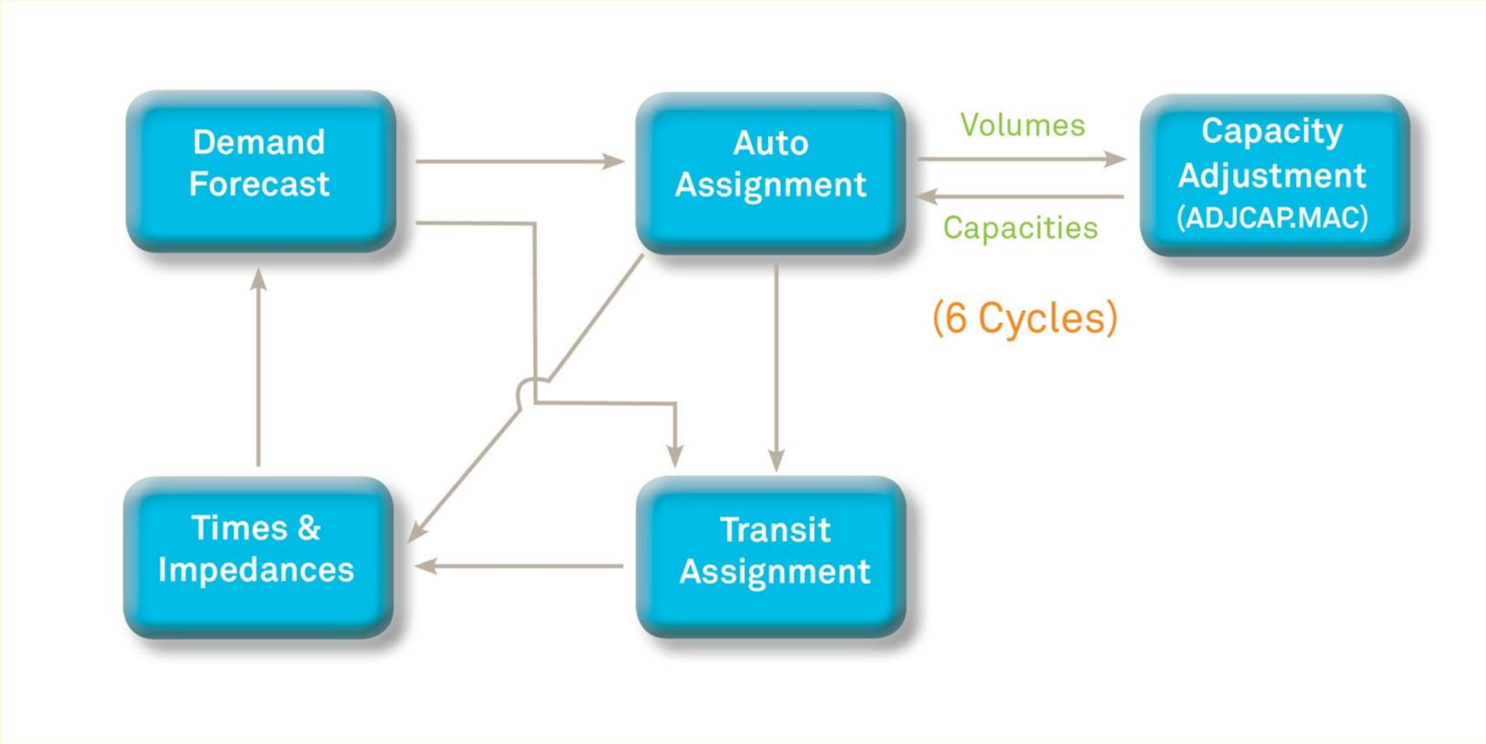
Intersection Modelling

- Used in Other Studies
- Primarily for Signalised Intersections
- Based on Signal Timing and Saturation Flows
- Impact of Conflicting Flows Generalised
- Fixed Turn Capacities
- Impressive Results

AECOM Approach

- Inclusion of Unsignalised Intersections
- Explicit Modelling of Conflicting Traffic
- Explicit Modelling of Capacities in Shared Lanes
- Iterative Procedure to Adjust Affected Capacities
- Procedures Based on HCM2010

Iterative Procedure



Signalised Intersections

Signalised Intersections

- Fixed Capacities for Protected Movements

$$c = s \frac{g}{C} N$$

- Variable Capacities
  - Permitted (and protected/permitted) LTs
  - Through and turn movements in shared lanes

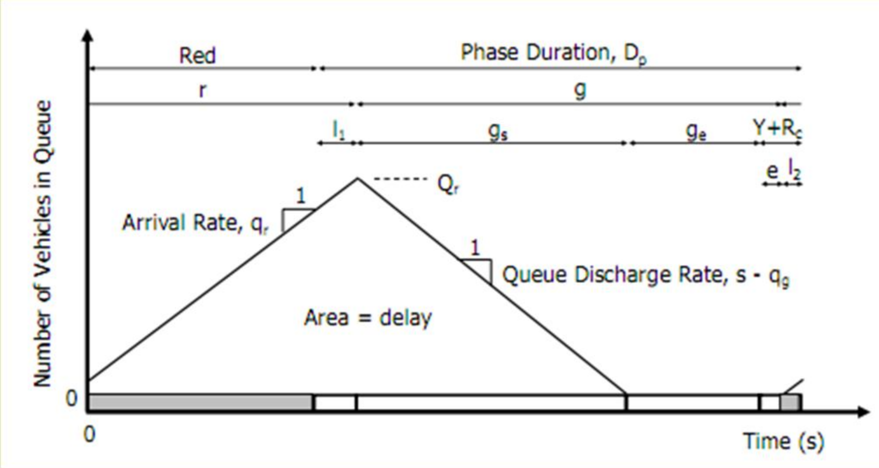
Signalised Intersections

- Permitted Left Turns
  - HCM 2010 Saturation Flow Rate Equation
  - Critical Headway 4.5 secs: Follow-up Headway 2.5 secs.

$$c_{pm} = \left(\frac{v_o e^{-4.5 v_o / 3600}}{1 - e^{-2.5 v_o / 3600}} \frac{g_u}{C} + \frac{2*3600}{C} \right) N$$

- v_o = opposing thru and RT volume from previous assignment
- C = cycle length
- N = number of permitted LT lanes
- g_u = green time (s) after clearance of initial queue of opposing traffic

Signalised Intersections

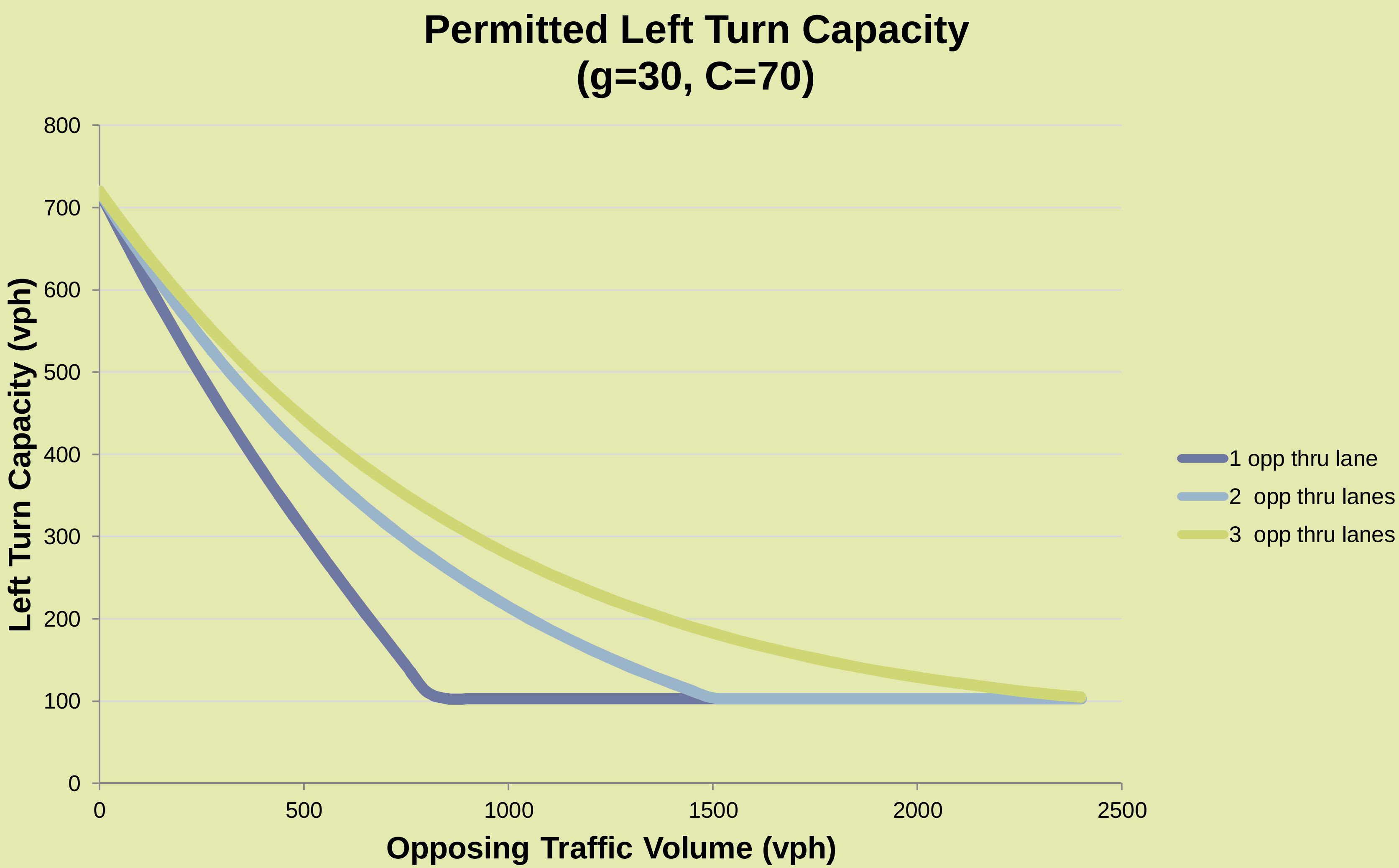


- Permitted Left Turns
  - Post-Queue Clearance Time

$$g_u = \left(\frac{g_{oT} * 1900 * N_{oT} - C * v_{oT}}{1900 * N_{oT} - v_{oT}} \right). \max .0$$

- g_{oT} = opposing through green time (s)
- N_{oT} = number of opposing through lanes
- v_{oT} = opposing through traffic volume (vph)

Signalised Intersections



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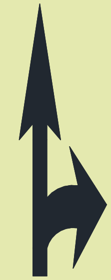
Signalised Intersections

- Shared Lanes
  - Shared thru and RT lane with no separate dedicated thru lane
  - Shared thru and LT lane with no separate dedicated thru lane
  - Shared thru and RT lane with parallel dedicated thru lane(s)
  - Shared thru and LT lane with parallel dedicated thru lane(s)
  - Shared thru and LT lane, shared thru and RT lane and at least one dedicated thru lane.
  - Shared thru and RT lane and a shared thru and LT lane
  - Single approach lane for the thru movement and both turns.

Signalised Intersections – Case 1 & 2

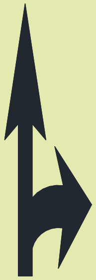


- Shared Thru/RT (or LT) lane, no separate thru lane
  - Based on “unshared” capacities and previous assigned volumes

$$c_{SH} = \frac{v_R + v_T}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{IT}}}$$

- v_R = right turn volume (vph) from previous assignment
- v_T = through volume (vph) from previous assignment
- c_{IR} = initial right turn capacity (vph) calculated for dedicated lane
- c_{IT} = initial through capacity (vph) calculated for dedicated lane

Signalised Intersections



- Shared Thru/RT (or LT) lane, no separate thru lane

$$c_R = c_{SH} \frac{v_R}{v_R + v_T} = \frac{v_R}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{IT}}}$$

$$c_T = c_{SH} \frac{v_T}{v_R + v_T} = \frac{v_T}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{IT}}}$$

$$\frac{v_R}{c_R} = \frac{v_T}{c_T} = \frac{v_R + v_T}{c_R + c_T}$$

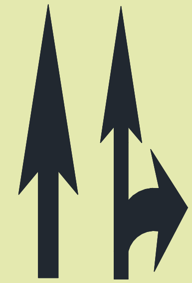
Signalised Intersections – Case 3 &4

- Shared thru/RT (or LT) lane, with separate thru lane
  - "Initial" capacities (c_{IR} *and* c_{IT}) assuming dedicated turn lane
  - If $$\frac{v_T}{c_{IT}} \leq \frac{v_R}{c_{IR}}$$
    - Through vehicles will not use the shared lane
    - Hence: $c_R = c_{IR}$ and $c_T = c_{IT}$

Signalised Intersections

- Shared thru/RT (or LT) lane, with separate thru lane
  - If $$\frac{v_T}{c_{IT}} > \frac{v_R}{c_{IR}}$$
    - Some through vehicles will use the shared lane
    - And *v/c* ratios for all lanes will be equal
    - Procedure utilises notional capacity c_{ET} for through capacity of shared lane.

Signalised Intersections



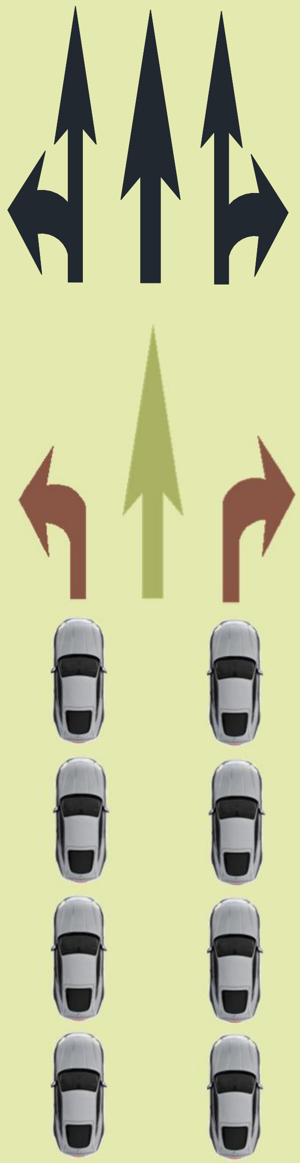
- Shared thru/RT (or LT) lane, with separate thru lane

$$c_R = \frac{v_R\left(1+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}} \qquad c_T = \frac{v_T\left(1+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}}$$

  - c_{ET} = additional capacity (vph) if shared lane was a dedicated through lane
  - c_R = total right turn capacity (vph) for next assignment cycle
  - c_T = total through capacity (vph) for next assignment cycle

$$\frac{v_R}{c_R} = \frac{v_T}{c_T} = \frac{v_R+v_T}{c_R+c_T}$$

Signalised Intersections – Case 5



- Thru/LT lane, thru/RT lane, 1+ thru lane
  - “Initial” capacities (c_{IR}, c_{IL} and c_{IT}) assuming dedicated turn lanes
  - If $$\frac{v_L}{c_{IL}} \geq \frac{v_T}{c_{IT}} \leq \frac{v_R}{c_{IR}}$$
    - Through vehicles will not use either shared lane
    - Hence: $c_R = c_{IR}$; $c_L = c_{IL}$ and $c_T = c_{IT}$

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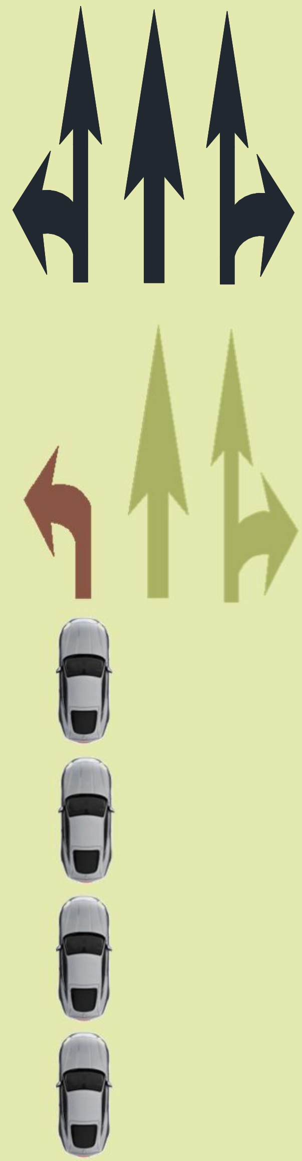
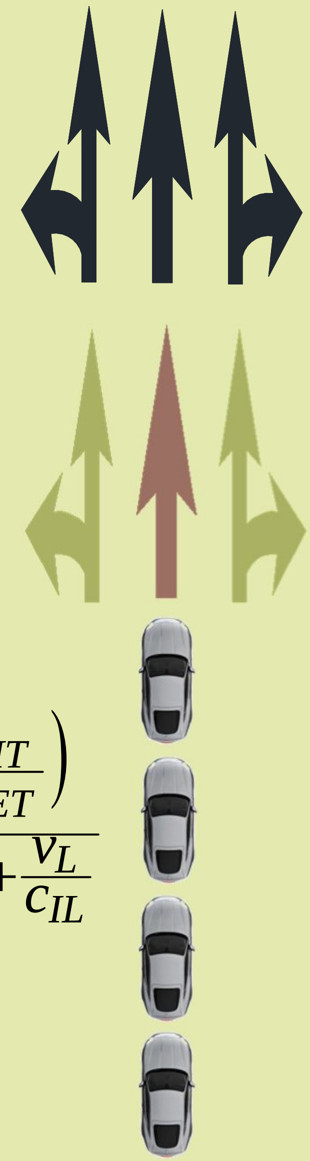
Signalised Intersections

- Thru/LT lane, thru/RT lane, 1+ thru lane
  - If $$\frac{v_L}{c_{IL}} \geq \frac{v_T}{c_{IT}} > \frac{v_R}{c_{IR}}$$
    - Thru vehicles will only use dedicated thru lane and shared thru/RT lane
    - $c_L = c_{IL}$; c_R and c_T calculated using shared lane procedure

$$c_R = \frac{v_R\left(1+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}} \qquad c_T = \frac{v_T\left(1+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}}$$



Signalised Intersections



- Thru/LT lane, thru/RT lane, 1+ thru lane
  - Finally, if $\dfrac{v_L}{c_{IL}} < \dfrac{v_T}{c_{IT}} > \dfrac{v_R}{c_{IR}}$
    - Thru vehicles will use both shared lanes
    - c_L ; c_R and c_T calculated using shared lane procedure

$$c_R = \frac{v_R\left(2+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}+\frac{v_L}{c_{IL}}} \qquad c_L = \frac{v_L\left(2+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}+\frac{v_L}{c_{IL}}} \qquad c_T = \frac{v_T\left(2+\frac{c_{IT}}{c_{ET}}\right)}{\frac{v_R}{c_{IR}}+\frac{v_T}{c_{ET}}+\frac{v_L}{c_{IL}}}$$

$$\frac{v_R}{c_R} = \frac{v_T}{c_T} = \frac{v_L}{c_L} = \frac{v_R+v_T+v_L}{c_R+c_T+c_L}$$

Signalised Intersections – Case 6

- Thru/LT lane, thru/RT lane only
  - If either but not both lanes overloaded

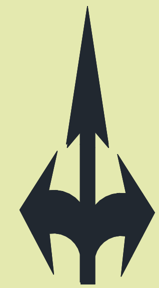
$$\frac{v_L}{c_{IL}} > 1 \quad \text{or} \quad \frac{v_R}{c_{IR}} > 1$$

    - Overloaded lane treated as dedicated
    - Remaining lane shared calculation follows case 1 (or 2)
  - In all other cases, thru vehicles will use both shared lanes

$$c_R = \frac{2v_R}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}} \qquad c_L = \frac{2v_L}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}} \qquad c_T = \frac{2v_T}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}}$$

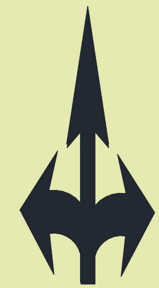
$$\frac{v_R}{c_R} = \frac{v_T}{c_T} = \frac{v_L}{c_L} = \frac{v_R + v_T + v_L}{c_R + c_T + c_L}$$

Signalised Intersections – Case 7



- Single lane approach
  - Left turn can block through and RT movements
  - If LT volume < 2 vehicles per cycle
    - Thru and RT will “squeeze” by waiting LT vehicles
    - Approach treated as LT lane and partially blocked shared thru/RT lane

Signalised Intersections



- Single lane approach
  - If LT volume > 2 vehicles per cycle
    - LT vehicles will block other vehicles
    - Full Shared Lane Procedure will apply

$$c_R = \frac{v_R}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}} \qquad c_L = \frac{v_L}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}} \qquad c_T = \frac{v_T}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{ET}} + \frac{v_L}{c_{IL}}}$$

$$\frac{v_R}{c_R} = \frac{v_T}{c_T} = \frac{v_L}{c_L} = \frac{v_R + v_T + v_L}{c_R + c_T + c_L}$$

Unsignalised Intersections

AECOM Approach

- Unsignalised Intersections
  - Two-Way Stop Control (TWSC)
    - Left Turns from Major Streets
    - Minor Streets Traffic Movements
  - All-Way Stops
  - Roundabouts
  - Highway On Ramps

Unsignalised Intersections

- TWSC Intersection
  - Left Turns from Major Streets
    - Based on HCM 2010 Procedures for "Rank 2" movements
    - For one or two opposing through lanes:

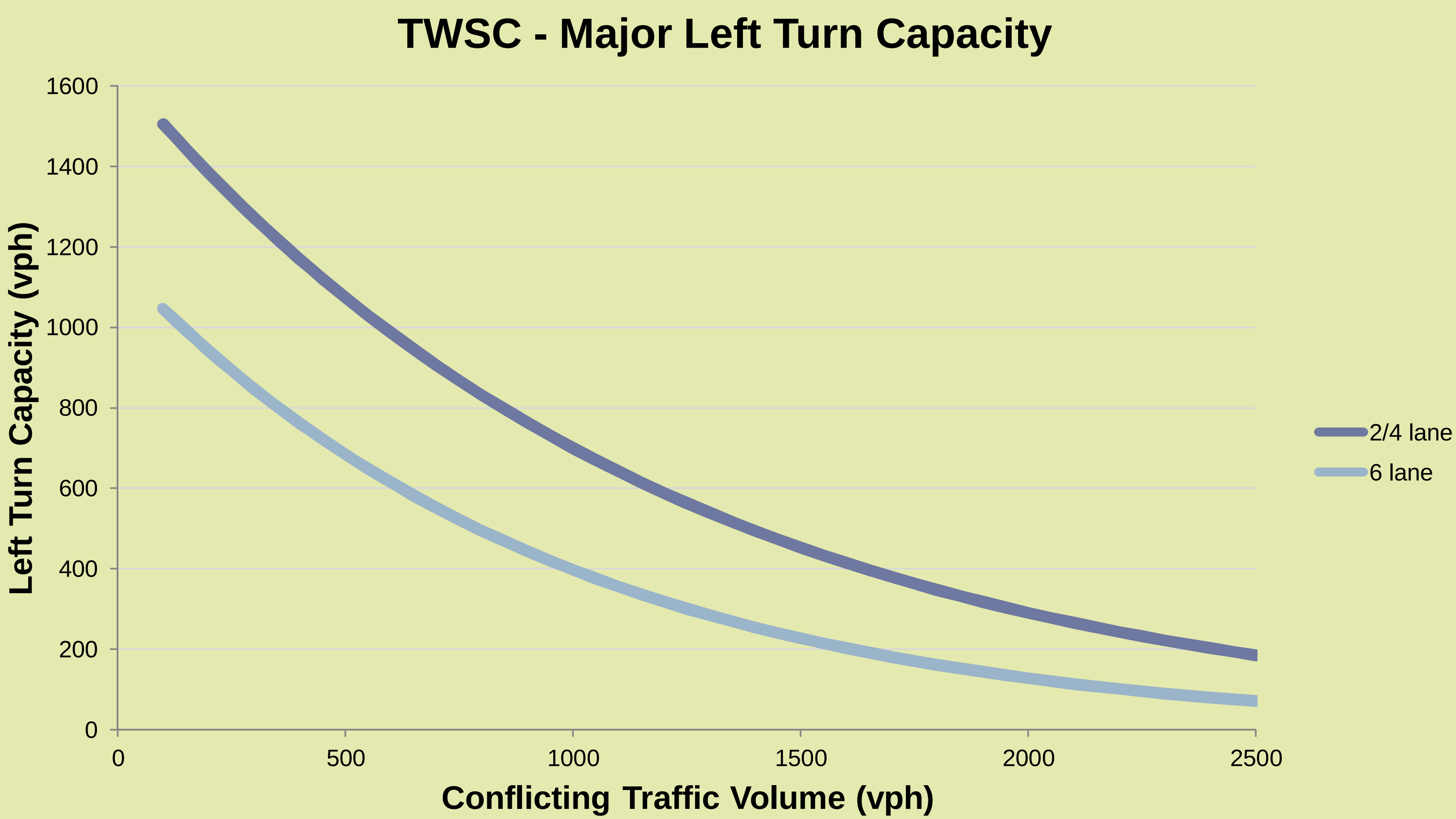
$$c = \frac{v_c e^{-4.1 v_c / 3600}}{1 - e^{-2.2 v_c / 3600}}$$

    - For more than two opposing through lanes:

$$c = \frac{v_c e^{-5.3 v_c / 3600}}{1 - e^{-3.1 v_c / 3600}}$$

    - v_c = conflicting volume = $v_{OT} + v_{OR} + v_{pedc}$

Unsignalised Intersections



Unsignalised Intersections

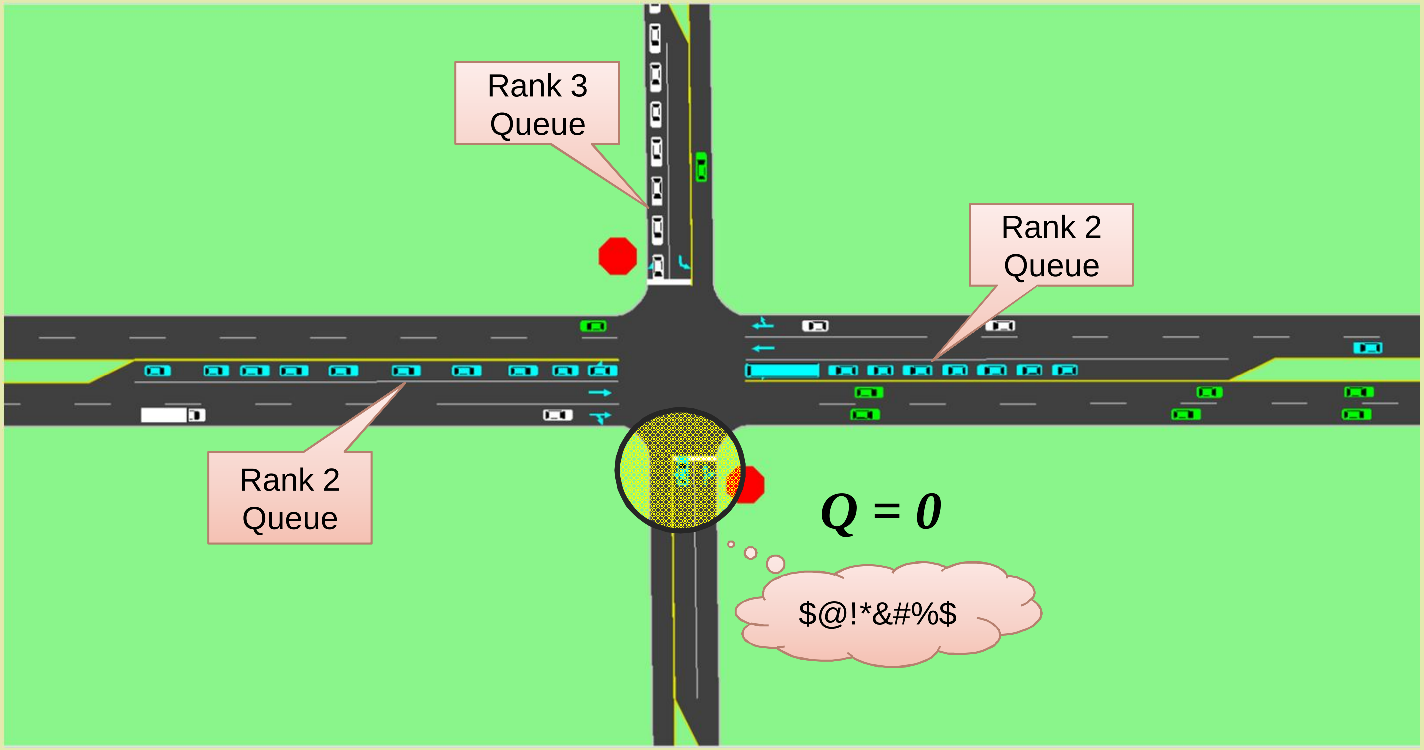
- TWSC Intersection
  - Minor Street Capacities
    - Simplified HCM 2010 Procedures for “Rank 3” and “Rank 4” movements
    - First, separate capacities calculated for RT, thru movements & LT

$$c_{Ij} = \frac{v_c e^{-6.7 v_c / 3600}}{1 - e^{-3.7 v_c / 3600}} * Q$$

- c_{Ij} = Initial capacity for movement j
- v_c = Conflicting volume from previous assignment
- Q = Probability that higher ranked movements are queue-free

Unsignalised Intersections

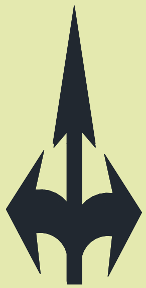
- TWSC Intersection
  - Minor Street Capacities
    - Q = Probability that higher ranked movements are queue-free



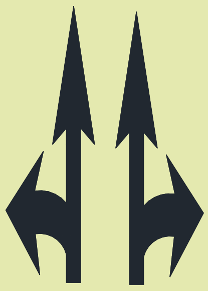
Unsignalised Intersections

- TWSC Intersection
  - Minor Street Capacities
    - Shared Single Lane

$$c_{SH} = \frac{v_R + v_T + v_L}{\frac{v_R}{c_{IR}} + \frac{v_T}{c_{IT}} + \frac{v_L}{c_{IL}}}$$



    - c_{SH} = Minor Road Approach Capacity (vph) saved as link attribute
    - Two-Lane Approach
    - Shared Lane Procedure for Signalised Intersection (Case 6) followed.



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Unsignalised Intersections

- All-Way Stops (& Mini-Roundabouts)
  - Simplified HCM 2010 Procedure
  - Departure Headway assumed 3.2 seconds
  - Basic capacity = 550 vphpl per leg
  - Adjustments for left turns and for unused conflicting capacity
  - Capacities saved as Link Attribute

Unsignalised Intersections

- Roundabouts
  - HCM 2010 Procedure
  - Capacity per entry lane conflicted by one circulating lane:

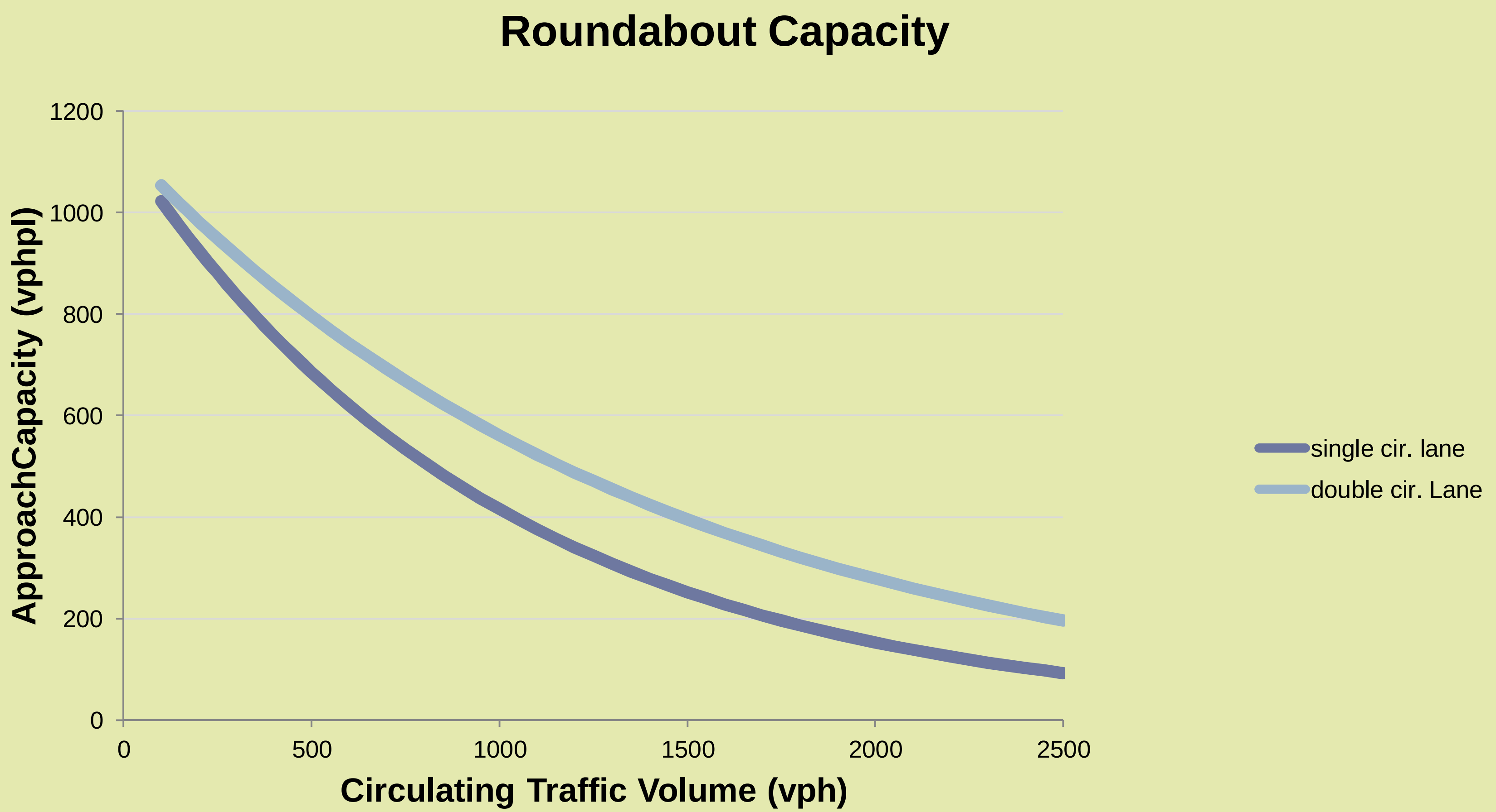
$$c = 1130e^{-0.001v_c}$$

  - Capacity per entry lane conflicted by two circulating lanes:

$$c = 1130e^{-0.0007v_c}$$

  - Capacities saved as Link Attribute

Unsignalised Intersections



Unsignalised Intersections

- Highway On Ramps
  - For ramp traffic merging with through traffic:

$$c_{Ramp} = c_T * N_T - v_T$$

  - For ramp traffic yielding to through traffic:

$$c_{Ramp} = c_T - \frac{v_T}{N_T}$$

    - c_T = Capacity of through highway lanes (assumed at 2000 vphpl)
    - N_T = Number of through highway lanes
    - v_T = Upstream through highway volume (vph) from previous assignment
  - Capacities saved as Link Attribute

Delay Calculations

- Turn Penalty Functions for intersection delay
- Volume Delay Functions (for 4-way stops, some 2-way stop movements, ramps and merges)
- Uniform Delay
- Congestion-Based Incremental Delay

Delay Calculations

- Uniform (Fixed) Delay (d_1)
  - For protected movements at signalised intersections:

$$d_1 = \frac{(C-g)^2}{2C}$$

  - Additional Fixed Delay for permitted (left turn) phases
  - Left turns from Major to Minor – d_1 = 0.05 minutes
  - Minor at 2-way stop – d_1 = 0.25 minutes
  - 4-way stop and mini-roundabout – d_1 = 0.2 minutes
  - Other Roundabouts – d_1 = 0.15 minutes
  - Merge, yield and some right turns have no fixed delay

Delay Calculations

- Variable (Congestion-based) Delay (d_2)
  - BPR-based formula for all intersections

$$d_2 = \left(\frac{v}{c}\right)^4$$

  - Conical-based formula is under investigation

Implementation

Implementation

- Capacities calculated using EMME macro – adjcap.mac
- Turn and link attributes used to calculate and store capacities
- Fixed attributes input as part of network coding
- Adjustable attributes calculated in adjcap.mac

Input (Fixed) Attributes

- @type — intersection control type identifier
- @lanes — number of lanes & indication of lane sharing
- @green — green time
- @cycle — cycle length
- @nema — approach direction code and type of phase
- @pedvo — sum of conflicting pedestrian volumes

Calculated (Variable) Attributes

- @assvo — assigned turn movement volumes from previous assignment
- @convo — sum of conflicting or higher ranked volumes from previous assignment
- @sfact — pedestrian-bicycle adjustment factor for right turns and left turns from one-way streets
- @tncap — turn capacity
- @lkcap — link capacity (for 4-way stops, some 2-way stop movements, ramps and merges)

Temporary Attributes

- ul1, ul2, ul3, up1, up2, up3 – used & reused in adjcap.mac
- el1 – Used in vdf for assignment as @lkcap
- ep1 – Used in tpf for assignment as @cycle
- ep2 – Used in tpf for assignment as @green
- ep3 – Used in tpf for assignment as @tncap

Validation Results

Prince George Transportation Study (Earlier Version)

- 100 Intersections Modelled
- Mean absolute error = 18 vehs/hr
- Mean absolute percentage error = 7.4%
- Mean GEH = 1.5
- Max GEH = 9
- R^2 = 0.986

Latest Version Being Applied in Study in Surrey

Thank You

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