RSG

the science of insight

# Modeling Intersection Delay in Static Assignment

May 11, 2016

# Agenda

## MOTIVATION

- Why do this?

## KEY ISSUES

- Things to think about

## METHODS

- Ways of doing it

## SUMMARY

Press Photo – Rex Larsen

# Motivation

# Why bother?

## GOOD REASONS

- Get speeds and delay right on arterials
  - Get emissions and vehicle operating costs right
  - Get routing right (better volumes, better paths for microsim)
- Represent rough benefits of different types of intersection control
  - Stop vs. Roundabout vs. Signal vs. Interchange

## MAYBE NOT

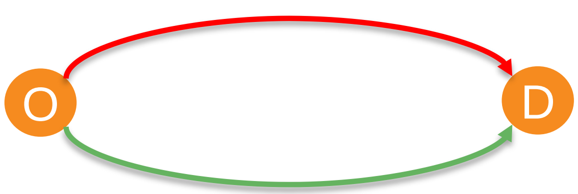
- Test signal improvements (re-timing, coordination)
  - Better to use Synchro, HCS, or microsimulation

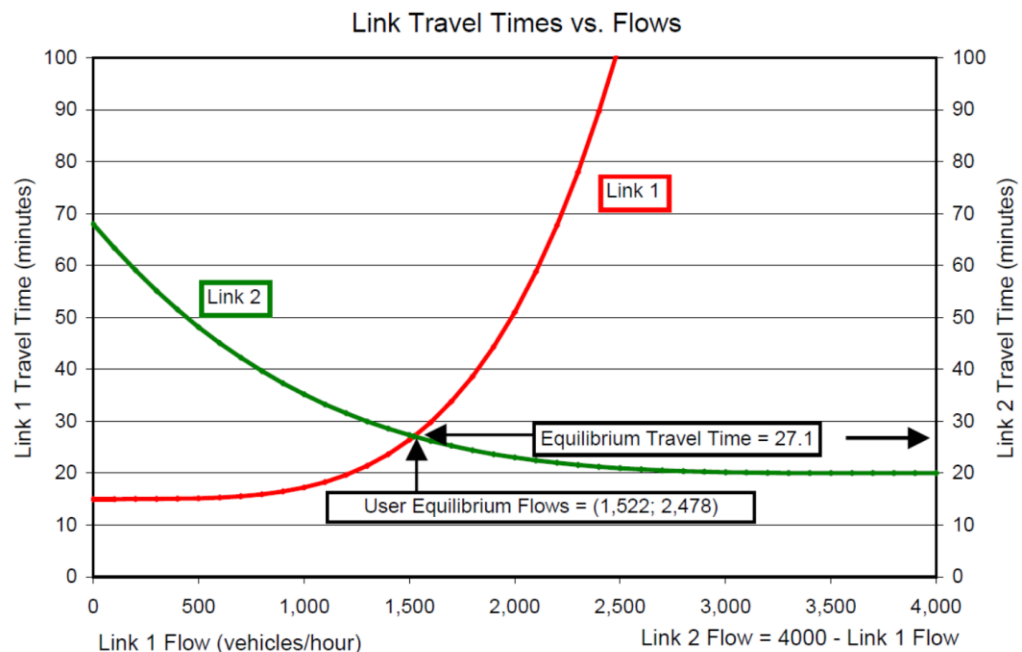
# Key Issues

# Solution Stability

## REQUIREMENTS FOR EXISTENCE OF UNIQUE, FIXED POINT SOLUTION

- The network is strongly connected
- Demand is non-negative, finite, and either fixed or continuous and decreasing in cost
- The cost function is positive, **continuous and increasing in demand**



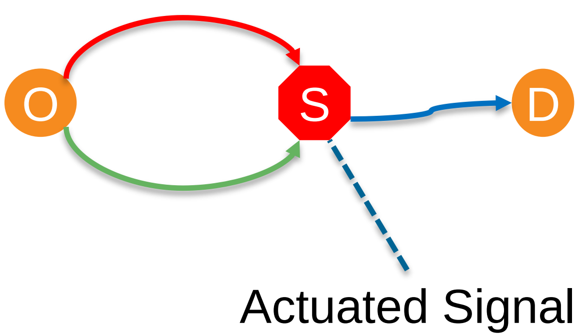



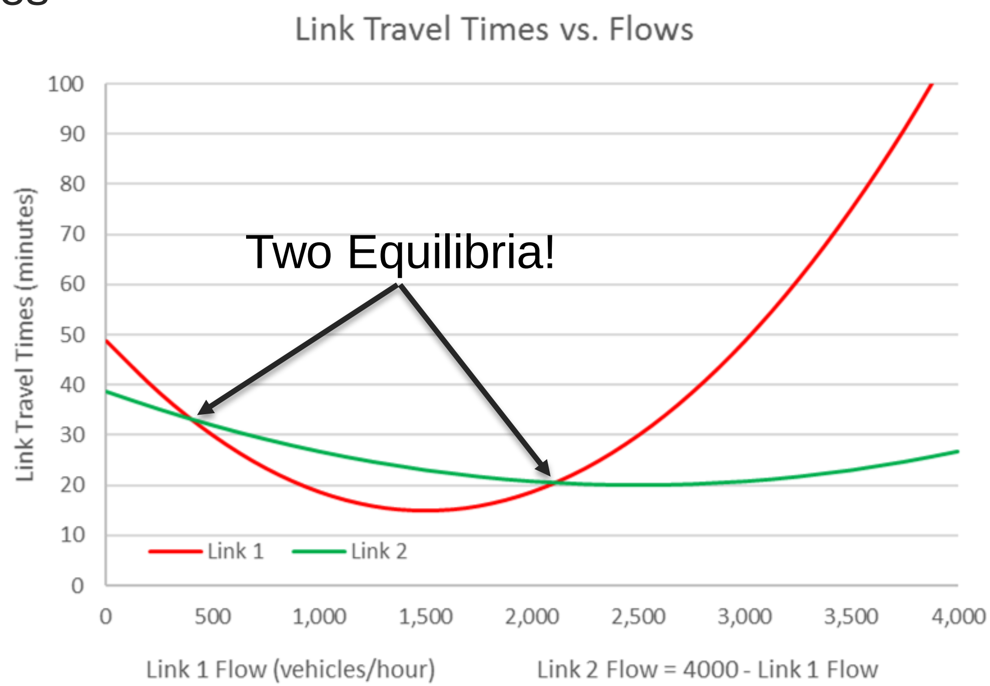

Source: D. Boyce

# Trouble with Intersections

## SIGNALS – ESPECIALLY ACTUATED – VIOLATE CONDITIONS

- cost function must be positive, **continuous and increasing in demand**
- cost can decrease at signals with the same or increasing demand if
  - timing changes/adapts or
  - cross street demand decreases
- multiple equilibria possible
- difference between two runs could just be this



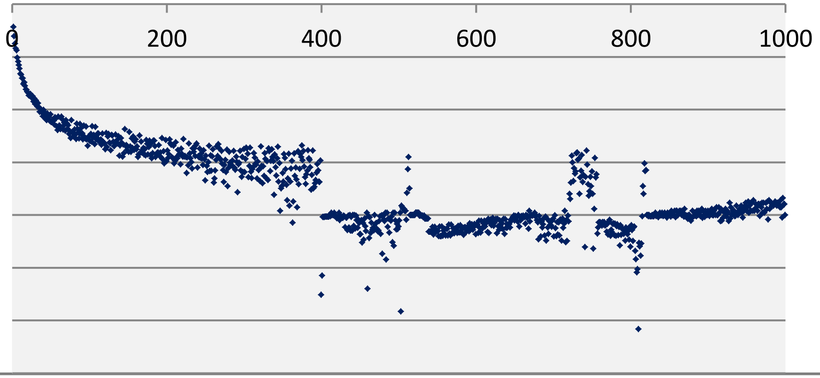
# So… Good enough?

## DANGER OF REALISTIC TRAFFIC DYNAMICS

- Realistic signal operations, etc., can threaten solution stability and invalidate (legally for NEPA) alternatives analysis, benefit-cost, and emissions analyses

## SO, INSTEAD…

- Most methods compromise between realism and solution stability
  - Make intersection delay as realistic as possible
  - While maintaining a stable solution
- Beware methods that don't compromise!



# Precision & Convergence

## PRACTICAL CONSIDERATIONS

- Well converged solutions are important
  - Considerable noise in poorly converged results
  - Is 800 vph +/- 2,000 vph really helpful?
- Some methods of incorporating intersection delay can require much longer run times to achieve the same convergence – or may not be able to achieve good convergence at all

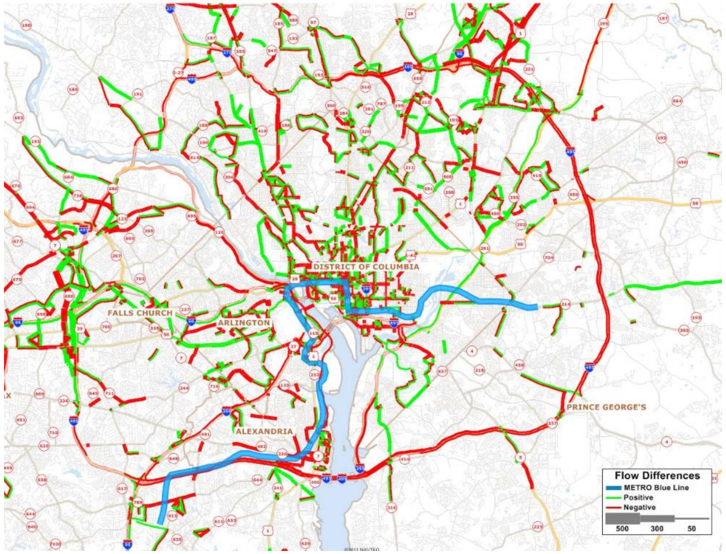


**Figure 2-3 Road Traffic Changes Due to Blue Line Service Improvement: Relative Gap = 0.01**

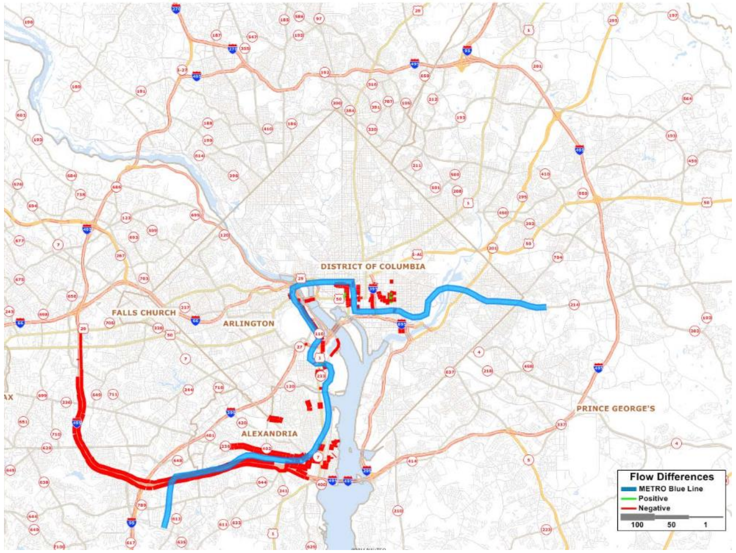


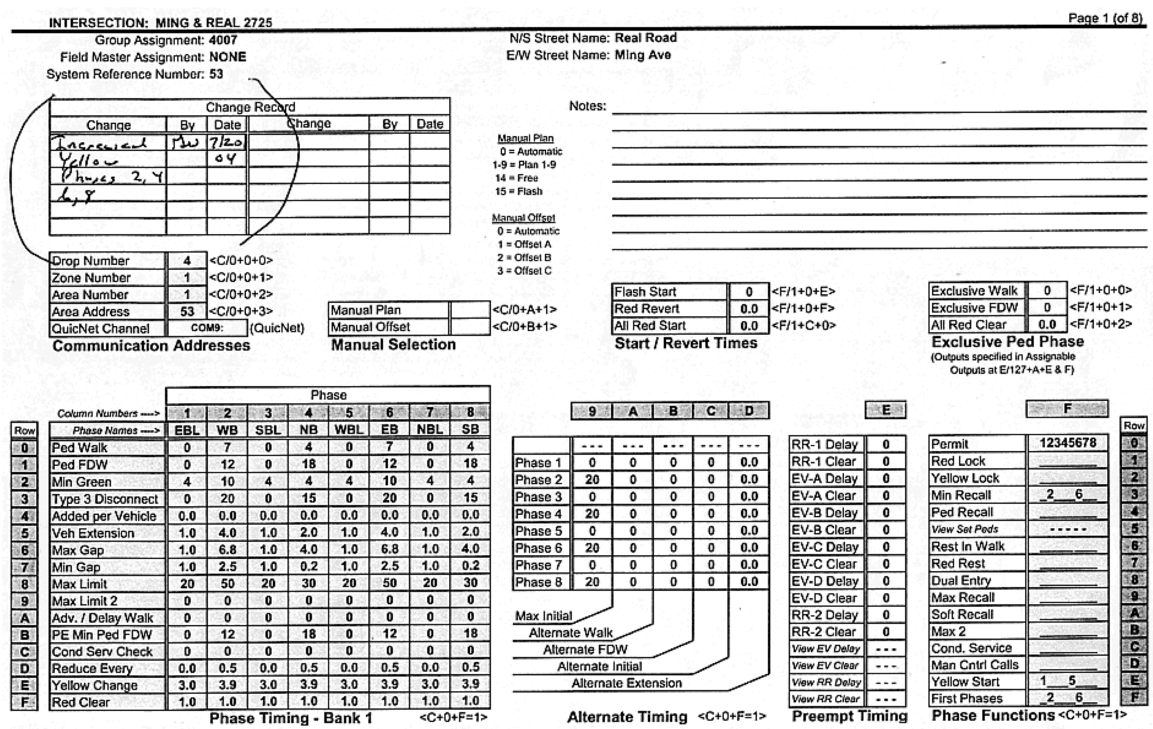
**Figure 2-4 Road Traffic Changes Due to Blue Line Service Improvement: Relative Gap = 0.000001**

Traffic Assignment and Feedback Research to Support Improved Travel Forecasting, FTA, 2015

# Input Data

## DATA HUNGRY?

- Different methods require different data
  - Location of signals & roundabouts (maybe stops)
  - g/C ratios, cycle length
  - Phasing, turn bay lengths, etc.



INTERSECTION: MING & REAL 2725 — Page 1 (of 8)

Group Assignment: 4007
Field Master Assignment: NONE
System Reference Number: 53

N/S Street Name: Real Road
E/W Street Name: Ming Ave

Change Record

| Change | By | Date | Change | By | Date |
|---|---|---|---|---|---|
| Increased Yellow Phases 2, 4 6, 8 | MW | 7/20 04 | | | |

Notes:

Manual Plan
0 = Automatic
1-9 = Plan 1-9
14 = Free
15 = Flash

Manual Offset
0 = Automatic
1 = Offset A
2 = Offset B
3 = Offset C

**Communication Addresses**

| | | |
|---|---|---|
| Drop Number | 4 | <C/0+0+0> |
| Zone Number | 1 | <C/0+0+1> |
| Area Number | 1 | <C/0+0+2> |
| Area Address | 53 | <C/0+0+3> |
| QuicNet Channel | COM9: | (QuicNet) |

**Manual Selection**

| | | |
|---|---|---|
| Manual Plan | | <C/0+A+1> |
| Manual Offset | | <C/0+B+1> |

**Start / Revert Times**

| | | |
|---|---|---|
| Flash Start | 0 | <F/1+0+E> |
| Red Revert | 0.0 | <F/1+0+F> |
| All Red Start | 0.0 | <F/1+C+0> |

**Exclusive Ped Phase**
(Outputs specified in Assignable Outputs at E/127+A+E & F)

| | | |
|---|---|---|
| Exclusive Walk | 0 | <F/1+0+0> |
| Exclusive FDW | 0 | <F/1+0+1> |
| All Red Clear | 0.0 | <F/1+0+2> |

**Phase Timing - Bank 1** <C+0+F=1>

| Row | Column Numbers ---> | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|
| | Phase Names ---> | EBL | WB | SBL | NB | WBL | EB | NBL | SB |
| 0 | Ped Walk | 0 | 7 | 0 | 4 | 0 | 7 | 0 | 4 |
| 1 | Ped FDW | 0 | 12 | 0 | 18 | 0 | 12 | 0 | 18 |
| 2 | Min Green | 4 | 10 | 4 | 4 | 4 | 10 | 4 | 4 |
| 3 | Type 3 Disconnect | 0 | 20 | 0 | 15 | 0 | 20 | 0 | 15 |
| 4 | Added per Vehicle | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | Veh Extension | 1.0 | 4.0 | 1.0 | 2.0 | 1.0 | 4.0 | 1.0 | 2.0 |
| 6 | Max Gap | 1.0 | 6.8 | 1.0 | 4.0 | 1.0 | 6.8 | 1.0 | 4.0 |
| 7 | Min Gap | 1.0 | 2.5 | 1.0 | 0.2 | 1.0 | 2.5 | 1.0 | 0.2 |
| 8 | Max Limit | 20 | 50 | 20 | 30 | 20 | 50 | 20 | 30 |
| 9 | Max Limit 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| A | Adv. / Delay Walk | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| B | PE Min Ped FDW | 0 | 12 | 0 | 18 | 0 | 12 | 0 | 18 |
| C | Cond Serv Check | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| D | Reduce Every | 0.0 | 0.5 | 0.0 | 0.5 | 0.0 | 0.5 | 0.0 | 0.5 |
| E | Yellow Change | 3.0 | 3.9 | 3.0 | 3.9 | 3.0 | 3.9 | 3.0 | 3.9 |
| F | Red Clear | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

**Alternate Timing** <C+0+F=1>

| | 9 (Max Initial) | A (Alternate Walk) | B (Alternate FDW) | C (Alternate Initial) | D (Alternate Extension) |
|---|---|---|---|---|---|
| | --- | --- | --- | --- | --- |
| Phase 1 | 0 | 0 | 0 | 0 | 0.0 |
| Phase 2 | 20 | 0 | 0 | 0 | 0.0 |
| Phase 3 | 0 | 0 | 0 | 0 | 0.0 |
| Phase 4 | 20 | 0 | 0 | 0 | 0.0 |
| Phase 5 | 0 | 0 | 0 | 0 | 0.0 |
| Phase 6 | 20 | 0 | 0 | 0 | 0.0 |
| Phase 7 | 0 | 0 | 0 | 0 | 0.0 |
| Phase 8 | 20 | 0 | 0 | 0 | 0.0 |

**Preempt Timing** (E) and **Phase Functions** (F) <C+0+F=1>

| Row | Preempt Timing | E | Phase Functions | F |
|---|---|---|---|---|
| 0 | RR-1 Delay | 0 | Permit | 12345678 |
| 1 | RR-1 Clear | 0 | Red Lock | |
| 2 | EV-A Delay | 0 | Yellow Lock | |
| 3 | EV-A Clear | 0 | Min Recall | 2 6 |
| 4 | EV-B Delay | 0 | Ped Recall | |
| 5 | EV-B Clear | 0 | *View Set Peds* | ----- |
| 6 | EV-C Delay | 0 | Rest In Walk | |
| 7 | EV-C Clear | 0 | Red Rest | |
| 8 | EV-D Delay | 0 | Dual Entry | |
| 9 | EV-D Clear | 0 | Max Recall | |
| A | RR-2 Delay | 0 | Soft Recall | |
| B | RR-2 Clear | 0 | Max 2 | |
| C | *View EV Delay* | --- | Cond. Service | |
| D | *View EV Clear* | --- | Man Cntrl Calls | |
| E | *View RR Delay* | --- | Yellow Start | 1 5 |
| F | *View RR Clear* | --- | First Phases | 2 6 |

# Dependencies on Input Data

## SELF-FULFILLING PROPHECIES

- Outcomes can be dependent on input assumptions (such as g/C, phasing, etc.) – even if the algorithm can adjust these
  - If the initial iteration has less delay for one movement, more demand gets assigned to it, so the algorithm maintains or increases the g/C / phasing ratio in favor of the movement…repeat ad infinitum
  - Not an issue in simpler schemes without phasing or variable g/C's

Other Self-Fulfilling Prophecies

# Calibration

## TO TRANSFER OR NOT TO TRANSFER

- Different methods have differing numbers and types of parameters
  - Some have observable parameters (e.g., cycle length, g/C)
  - All have calibration parameters
    - Some have well-established defaults
    - Others do not and may vary by location
- Ideal calibration requires having both travel time / delay and volume data for the same time periods
  - Travel time data now becoming more common – but often detailed (hourly / 15-min) counts are lacking
- Calibration can also be done by minimizing squared error versus counts in assignment

# Methods

# Overview of Methods

## METHODS FOR INTERSECTION DELAY IN STATIC ASSIGNMENT

- **Link / Approach-based**
  - **Link/Approach-based with Simple BPR form vdf**
  - **Link/Approach-based with “Double”/“Modified” BPR vdf**
  - Others (Aashtiani *et al.*)
- **Node Delay**
  - **IIT Logit Delay**
  - TMODEL Node Delay
- **HCM-based Volume-Dependent Turn Delays**
  - **Full HCM method**
  - HCM approach method
- Others?

# Link-based w/ Simple BPR form vdf

## A SIMPLE METHOD

- Webster's uniform control delay for free-flow conditions added to free-flow time for each approach

$$d_0 = 0.5C\left(1 - \frac{g}{C}\right)^2$$

- BPR form volume-delay function used to represent flow-dependent delays (uniform, random arrival / incremental & overflow / queueing delays)

$$t = (t_0 + d_0)\left[1 + \alpha\left(\frac{v}{c}\right)^\beta\right]$$

## NOTES

- Used in IN, KY, TN, AR, etc.
- Delay continuously increasing in demand
- Only requires intersection type (g/C can be assumed or input, etc.)
- Parameters ($\alpha$, $\beta$) different from freeways and vary by location

# Link-based w/ "Double"/"Modified" BPR vdf

## A PRETTY SIMPLE METHOD

- One BPR form volume-delay function for link / mid-block delay

$$t_l = t_0 \left[1 + \alpha_l \left(\frac{v}{c}\right)^{\beta_l}\right]$$

- Another BPR form volume-delay function used to represent flow-dependent delays (uniform, incremental / random arrival & overflow/queueing delays)

$$t_n = d_0 \left[1 + \alpha_n \left(\frac{v}{c}\right)^{\beta_n}\right]$$

## NOTES

- Used in AZ, CA, AK
- Delay continuously increasing in demand
- Only requires intersection type (g/C can be assumed or input, etc.)
- Need four parameters, vary by location

# Node Delay – IIT Logit

$$t_n = p_1 d_0 \left[1 + \left(\frac{p_2}{1 + e^{\left(p_3 - p_4 \frac{v}{c}\right)}}\right)\right]$$

## A DIFFERENT METHOD

- Logit delay function (from IIT) – one for link delay, one for node delay

## NOTES

- Used in NY, VT, NH
- Delay continuously increasing in demand
- Requires intersection / node capacities
  - Estimated at right from Synchro
- Requires lane configurations
- Fairly established parameters

**Signalized Intersection 24-Hour Capacity Values***

| Major Lane Group \ Minor Lane Groups | Single | Left Turn Bays | Left & Right Turn Bays | Left & 2 Through | Left, Right & 2 Through | 2 Throughs | 3 Throughs | Left & 3 Through | Left, Right and Three Through |
|---|---|---|---|---|---|---|---|---|---|
| Single | 23,000 | | | | | | | | |
| Left Turn Bays | 28,000 | 33,000 | | | | | | | |
| Left & Right Turn Bays | 31,000 | 36,000 | 38,000 | | | | | | |
| Left & 2 Through | 40,000 | 44,000 | 49,000 | 53,000 | | | | | |
| Left, Right & 2 Throughs | 46,000 | 50,000 | 54,000 | 58,000 | 62,000 | | | | |
| 2 Throughs | 29,000 | 33,000 | 37,000 | 39,000 | 43,000 | 35,000 | | | |
| 3 Throughs | 32,000 | 36,000 | 40,000 | 46,000 | 46,000 | 38,000 | 40,000 | | |
| Left & 3 Through | 48,000 | 52,000 | 56,000 | 60,000 | 64,000 | 50,000 | 54,000 | 66,000 | |
| Left, Right and Three Through | 50,000 | 54,000 | 58,000 | 62,000 | 66,000 | 52,000 | 56,000 | 68,000 | 72,000 |

# HCM-based Volume-Dependent Turn Delays

## A COMPLEX METHOD

- At each iteration, solve HCM for delay for each movement – update turn penalty to reflect this
- Can use full (critical movement) or simplified (approach) HCM method

## NOTES

- Used in OH
- Delay NOT continuously increasing in demand with full HCM – mostly stable in practice, but…
- Significant runtime increase
- Limits convergence
- Requires lane configurations
- Fairly established parameters

**Example 3-1: Critical Movement Analysis**

Step 1:
Lane configuration, phasing, and volumes:


Steps 2, 3, and 4:
Check east-west critical lane volumes to determine the pair of consecutive movements that requires the most time:
EB LT + WB TH/RT = 120 + (360 + 110)/2 = 120 + 235 = 355
WB LT + EB TH/RT = 170 + (690 + 280)/2 = 170 + 485 = 655 ← critical

Check north-south critical lane volumes to determine the pair of consecutive movements that requires the most time:
NB LT + SB TH/RT = 80 + 400 = 480 ← critical
SB LT + NB TH/RT = 120 + 210 = 330

Identify critical movements: WB LT, EB TH/RT, NB LT, SB TH/RT
Determine the sum of critical movement volumes: $CS$ = 655 + 480 = 1135

Steps 5, 6, and 7:
Determine the reference sum (capacity): $RS = 1530 \times PHF \times f_a = 1530 \times 1.00 \times 1.00 = 1530$
$PHF$ = Peak Hour Factor (assumed to be 1.00 in this example)
Adjustment factor for area type, $f_a$ = 0.90 for Central Business District, 1.00 for other (assumed to be "other" in this example)
Identify cycle length: $C$ = 120 s (assumed)
Determine total lost time: $L$ = 4 critical phases × 4 s per phase = 16 s

Calculate and assess intersection volume-to-capacity ratio:

$$X_{cm} = \frac{CS}{RS\left(1-\frac{L}{C}\right)} = \frac{1135}{1530\left(1-\frac{16}{120}\right)} = 0.86 \rightarrow \text{Near capacity}$$

# Summary

# Methods and Issues

## AT THE RISK OF REALLY OVERSIMPLIFYING…

| | Stable | Runtime / Convergence | Input Data Required | Self-Fulfilling Prophecy | Calibration |
|---|---|---|---|---|---|
| **Link / Approach-based** | | | | | |
| Link/Approach-based with Simple BPR form vdf | ☺ | ☺ | ☺ | ☺ | ☹ |
| Link/Approach-based with “Double”/“Modified” BPR vdf | ☺ | ☺ | ☺ | ☺ | ☹ |
| Others (Aashtiani *et al.* ) | ☺ | ☺ | ☺ | ☺ | ☹ |
| **Node Delay** | | | | | |
| IIT Logit Delay | ☺ | ☺ | ☹ | ☺ | ? |
| TMODEL Node Delay | ☺ | ☺ | ☺ | ☺ | ☹ |
| **HCM-based Volume-Dependent Turn Delays** | | | | | |
| Full HCM method | ☹ | ☹ | ☹ | ☹ | ☺ |
| HCM approach method | ☺ | ? | ☹ | ☹ | ☺ |


# Contacts

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