Contraflow Left-Turn Lane Design at Signalized Intersections

TexITE Houston Chapter Meeting

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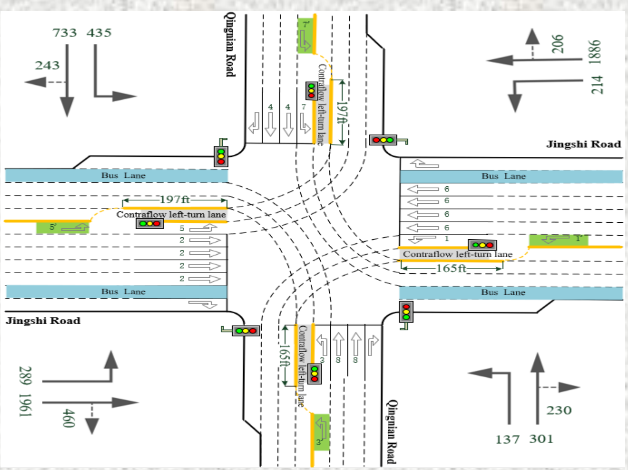
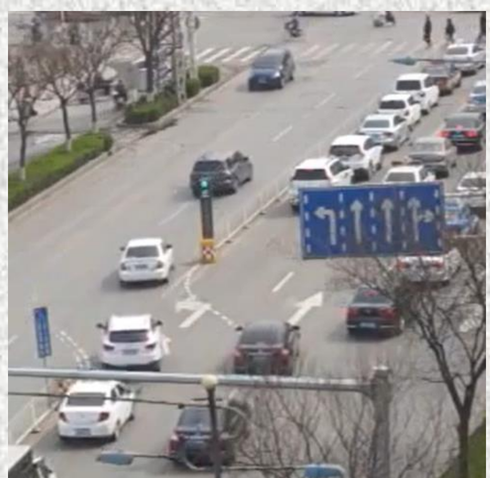
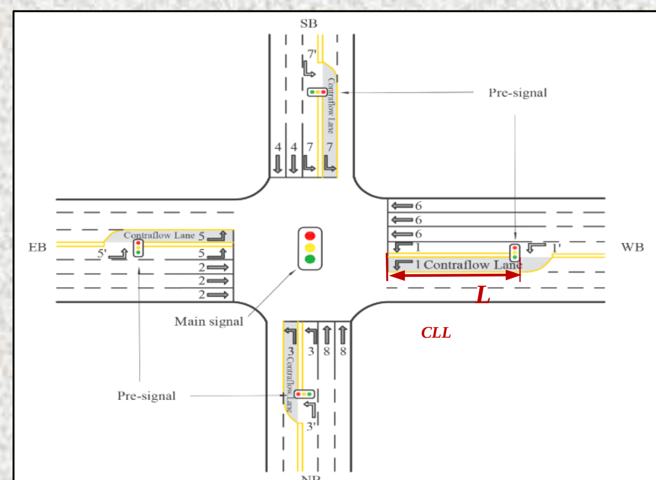
Texas Southern University

February 9, 2022







Texas Southern University

- **Texas Southern University** (TSU) is founded in 1927, 2nd largest Historically Black Colleges and University (HBCU) in the nation
- M.S. in Transportation Planning and Management at TSU (1983)
  - Planning and Policy
  - Systems and Technology
  - Freight and Logistic
  - Maritime Transportation

https://transportation.tsu.edu/

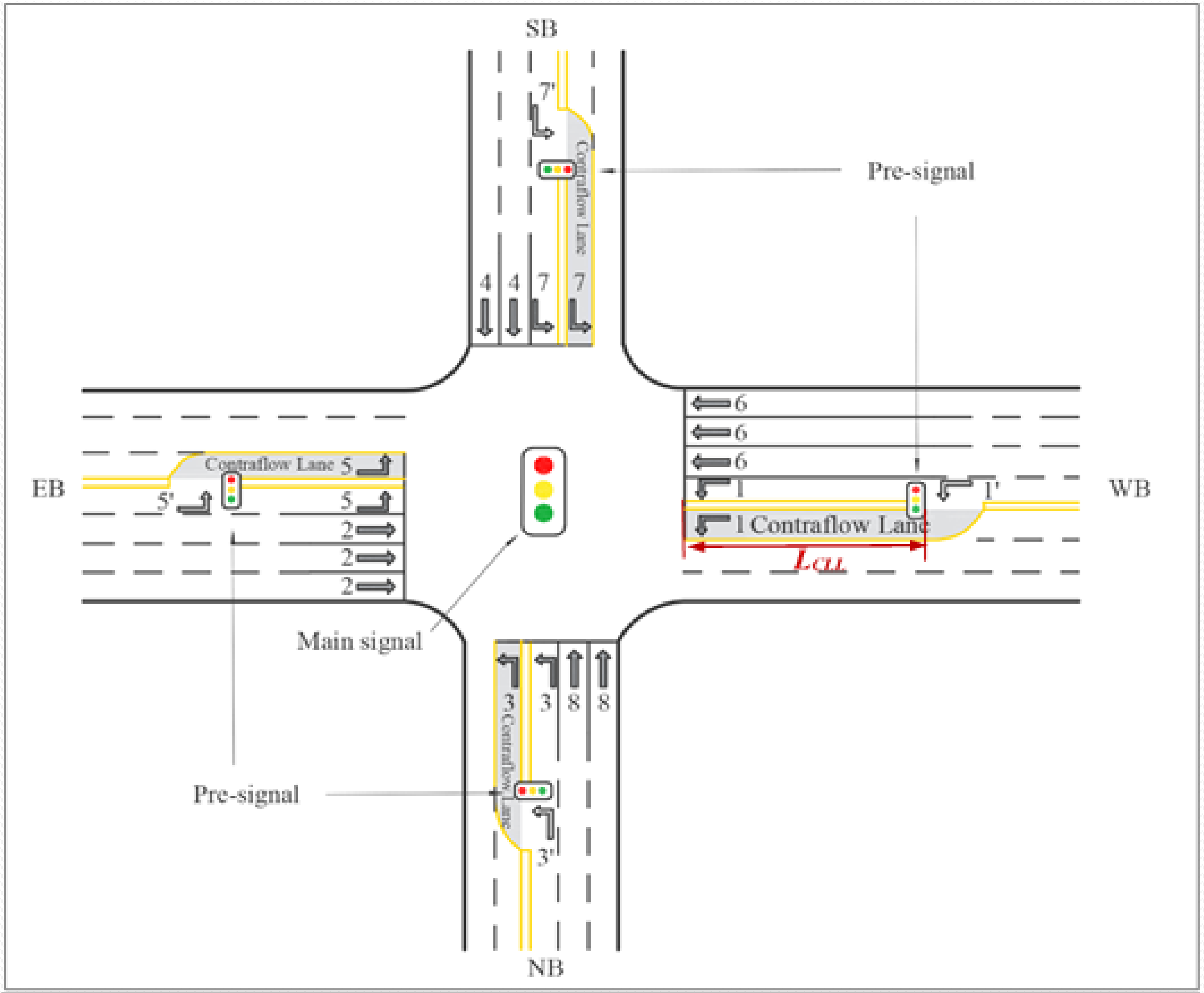
TSU

Outline

- Contraflow Left-Turn Lane Design
- Its Benefits and Safety Concerns
- Its Signal Timing and Geometric Design
- Use it with split phasing
- Conclusions and Recommendations

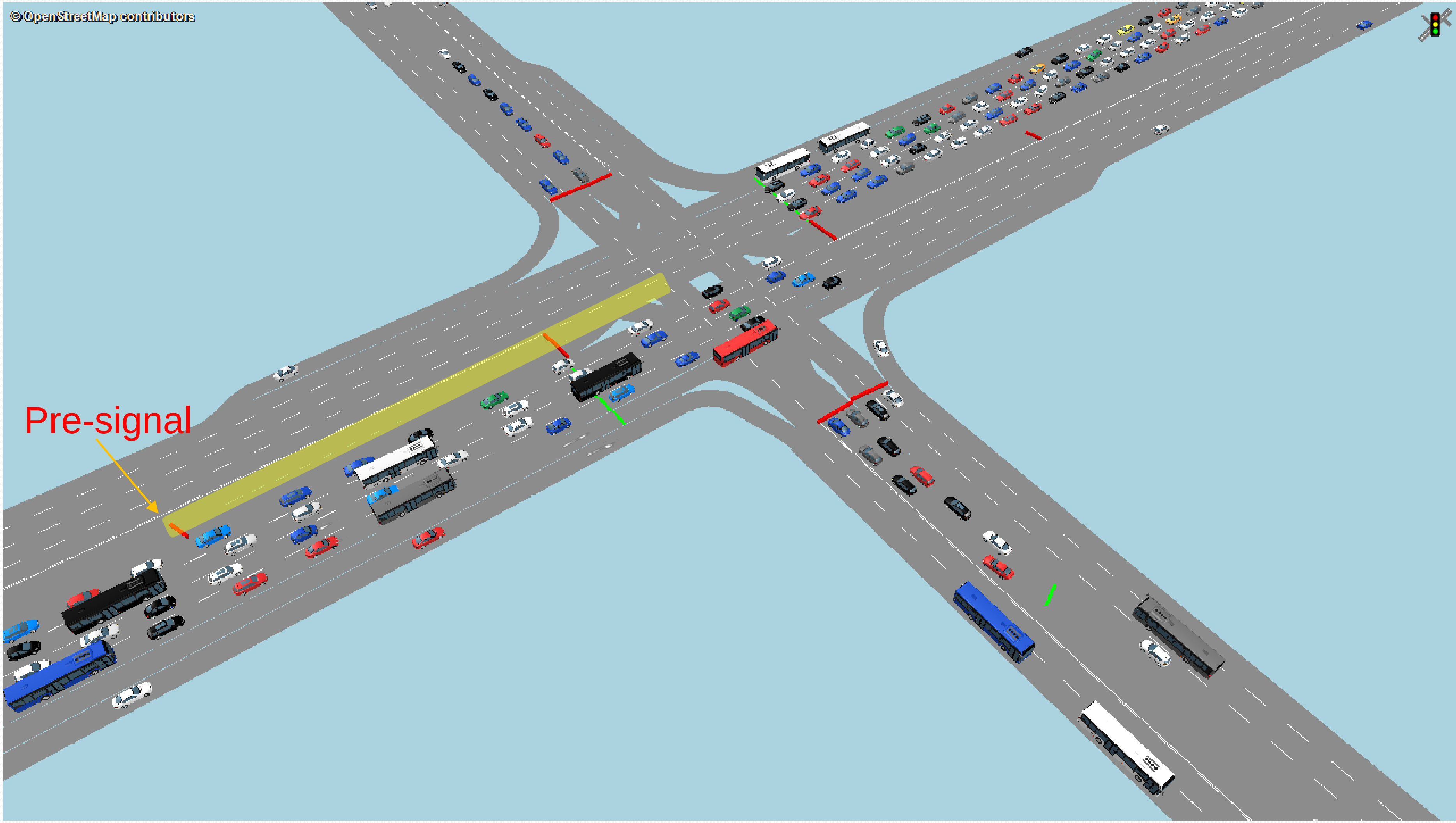
Contraflow Left-Turn Lane Design

- It provides additional left-turn capacity by making use of the opposing lanes dynamically through appropriate traffic signal control.



First implemented in china in 2014. After that, it has been widely implemented in more than 21 different cities in China by 2018 (Zhao et al., 2018).

Traffic simulation



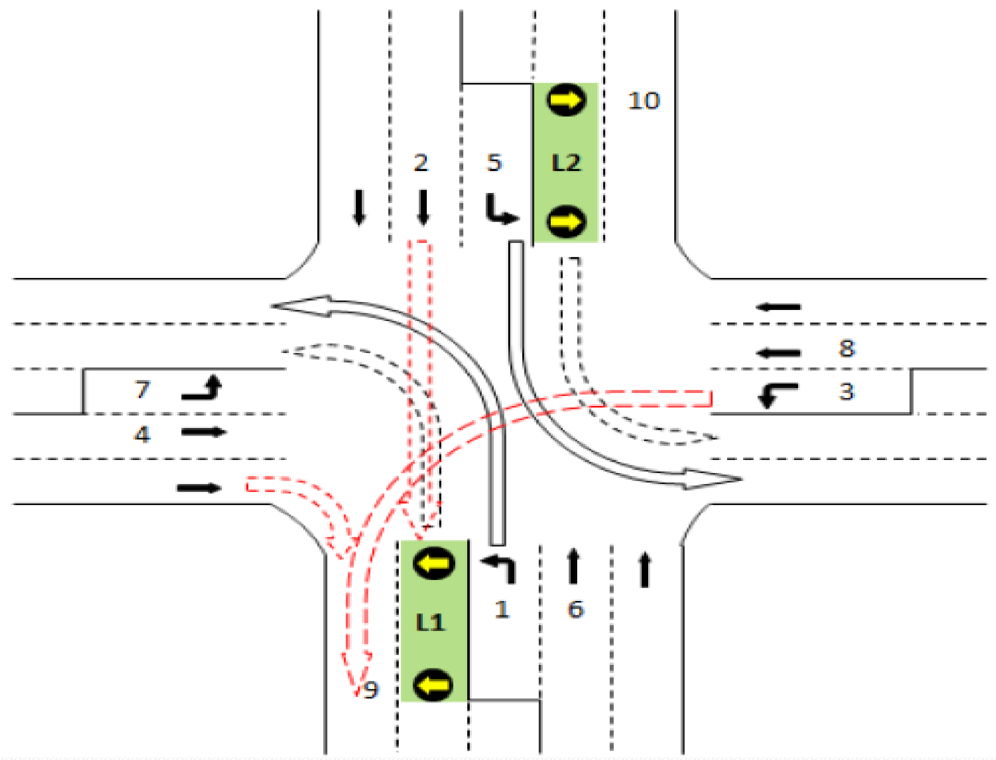
Real World CLL intersection

Benefits

- It increases intersection left-turn capacity, thereby reducing traffic delay and congestions at the intersections
- It can be easily implemented without modifying the intersection in a way that requires major constructions.
- It can also be easily converted back

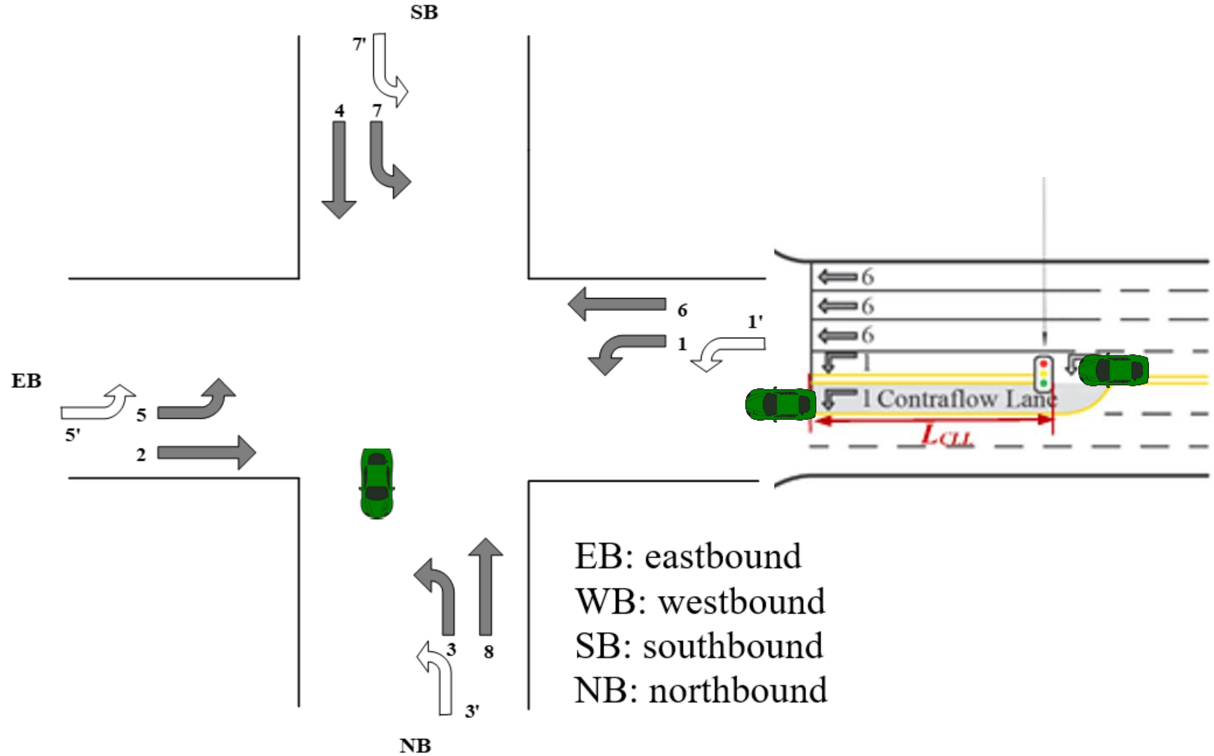
Safety Concerns

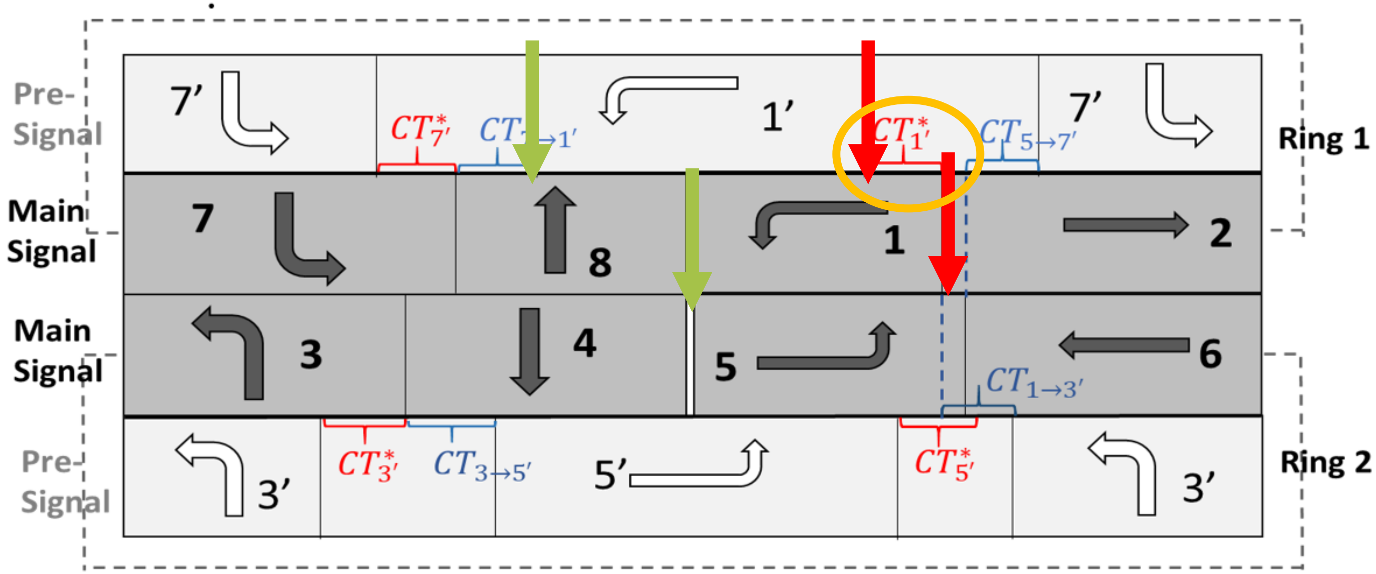
- The potential conflicts between the left-turn vehicles trapped on the CLL and opposing through vehicles
- Several movements conflicting with contraflow left-turn vehicles



Signal Timing and Geometric Design Requirements

Signal Timing

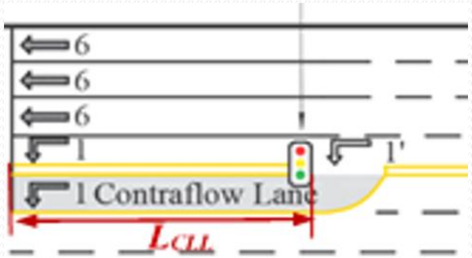




Signal timing requirements

- Sufficient clearance time for clearing the left-turn vehicles on the CLLs at the end of the pre-signal phase (end-clearance time).

$$CT_{i'}^{*} \geq t_{dh} * \frac{L_{CLL_i}}{S_{pc}} + l_s,\ i=1, 3, 5, 7.$$



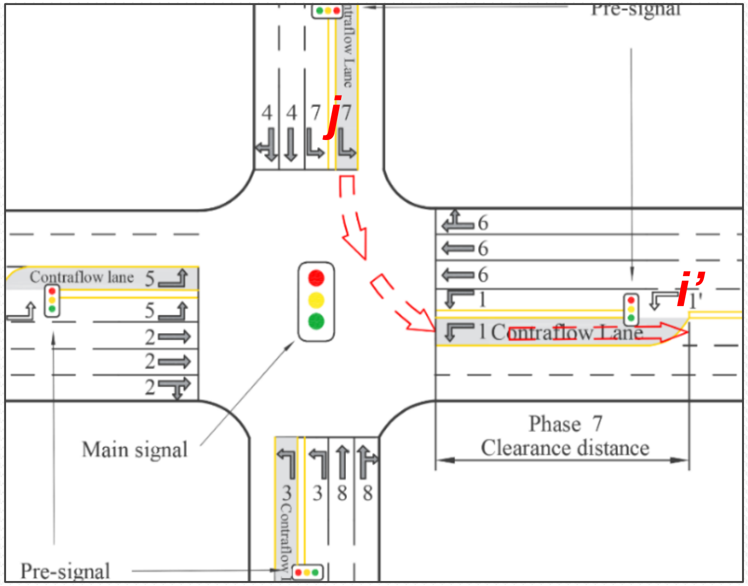
  - S_{pc} is the average vehicle storage length
  - t_{dh} is the saturation discharging headway
  - l_s is the start-up lost time

Signal timing requirements (Cont.)

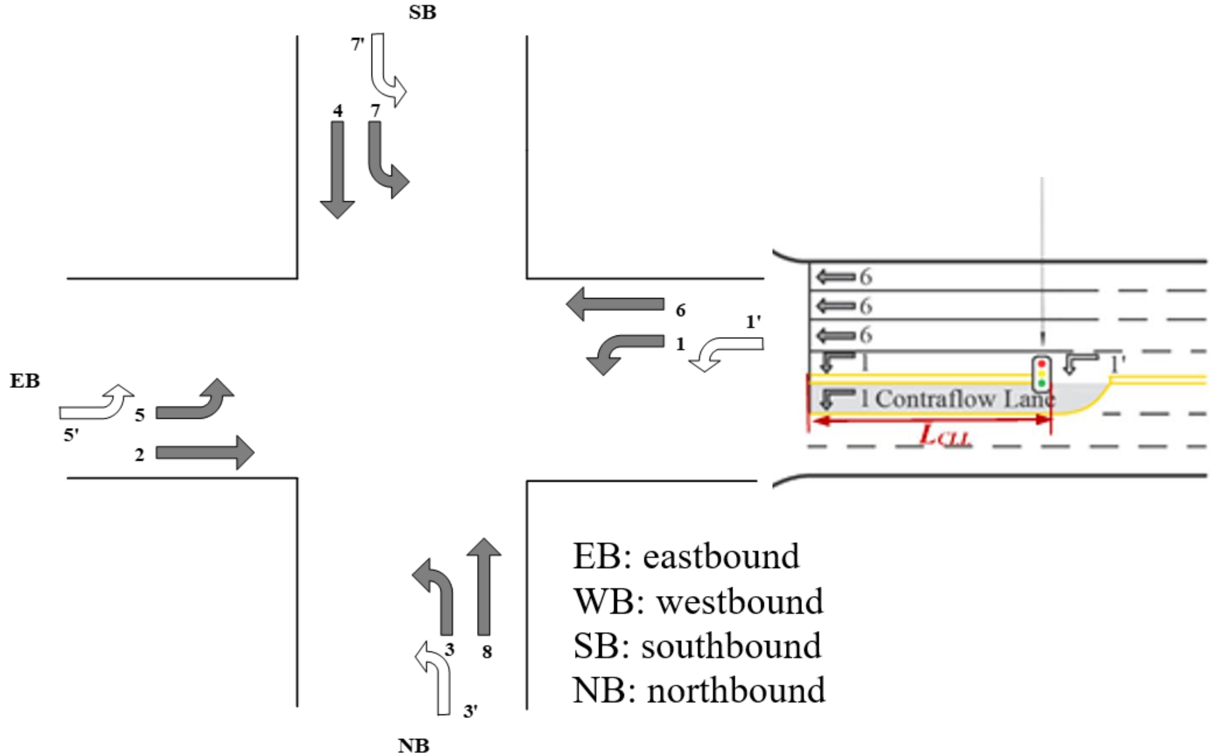
- Sufficient clearance time for clearing the conflicting left-turn vehicles from the cross street on the right side before starting the pre-signal phase (pre-clearance time)

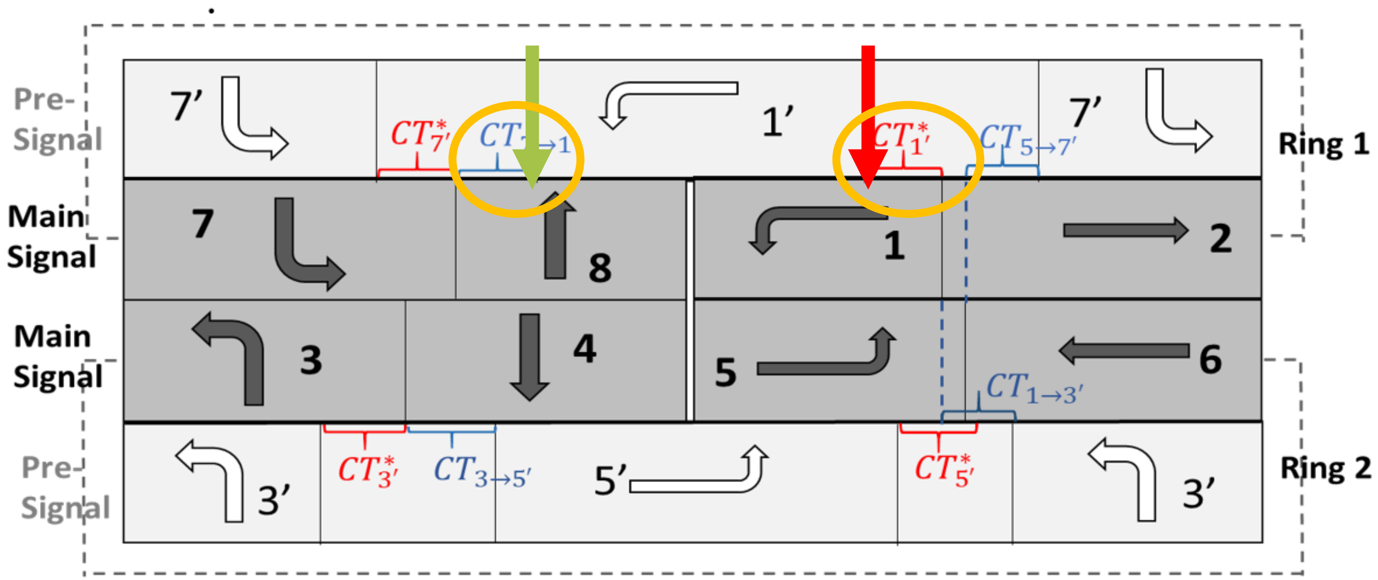
$$CT_{j-i'} \geq \frac{L_{CLL_i}}{1.47V_{15\%}}$$

- $CT_{j-i'}$ is the pre-clearance time for clearing the conflicting left-turn movement *j* from the CLL before starting the pre-signal phase *i*',
- L_{CLL_i} is the length of CLL
- $V_{15\%}$ is the 15th percentile approach speed or speed limit



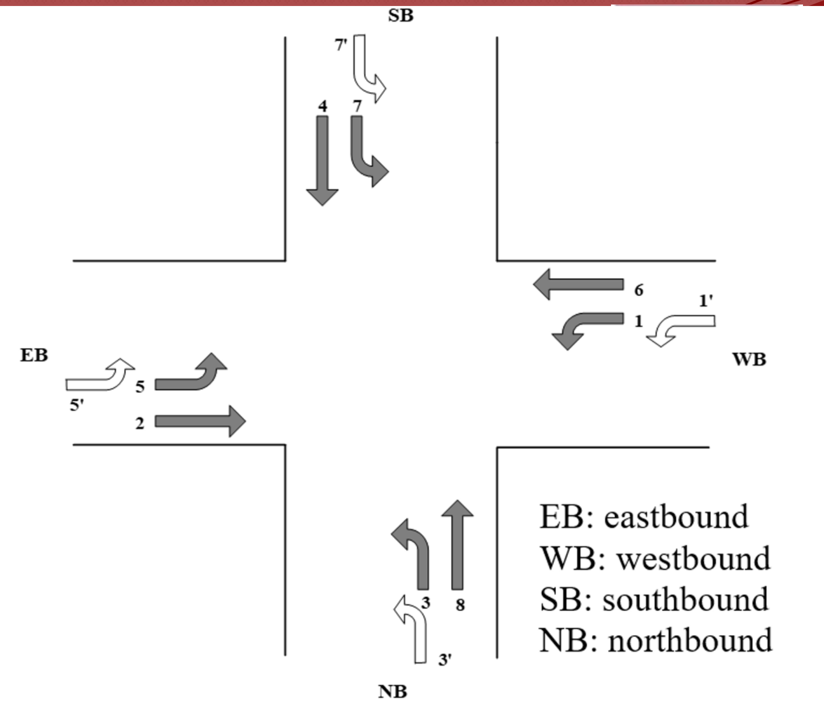
Signal Timing

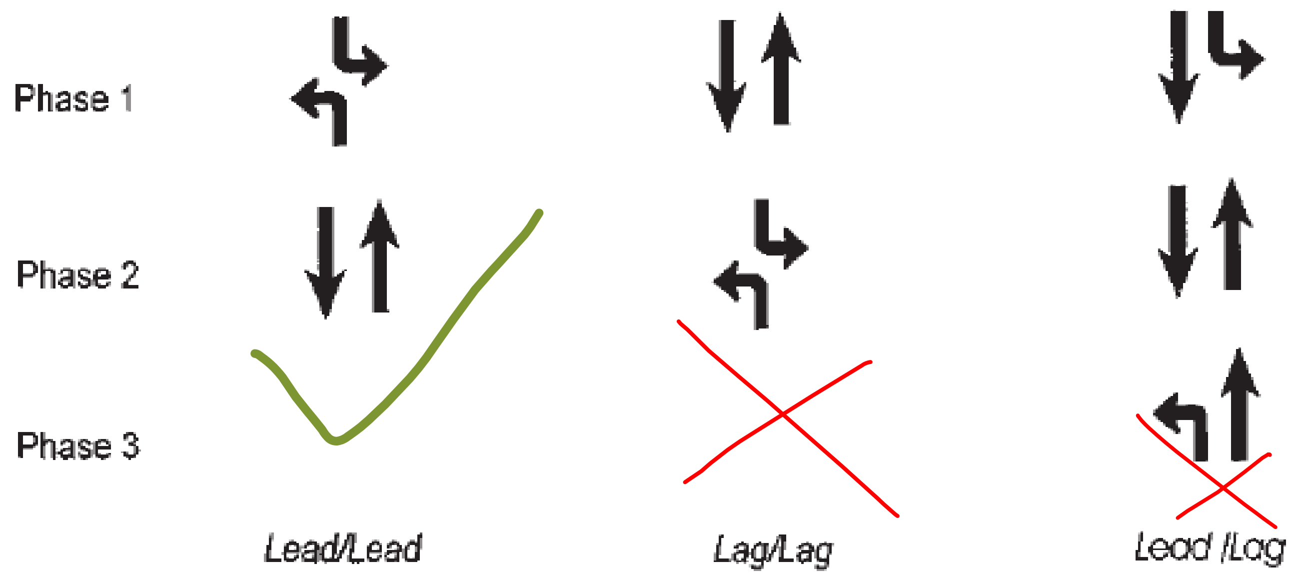




Signal timing requirements

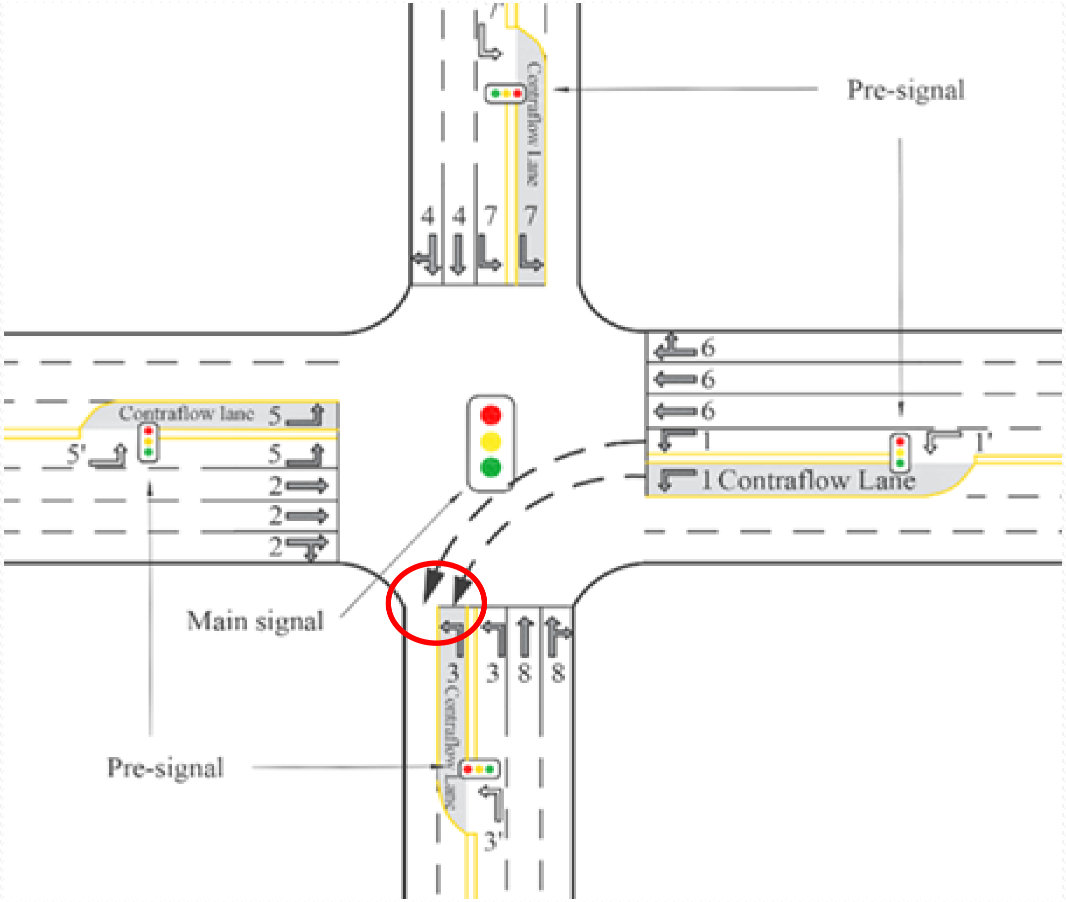
- **lead-lead protected LT only** & It can't work with the lagging left-turn phase (Limitation):





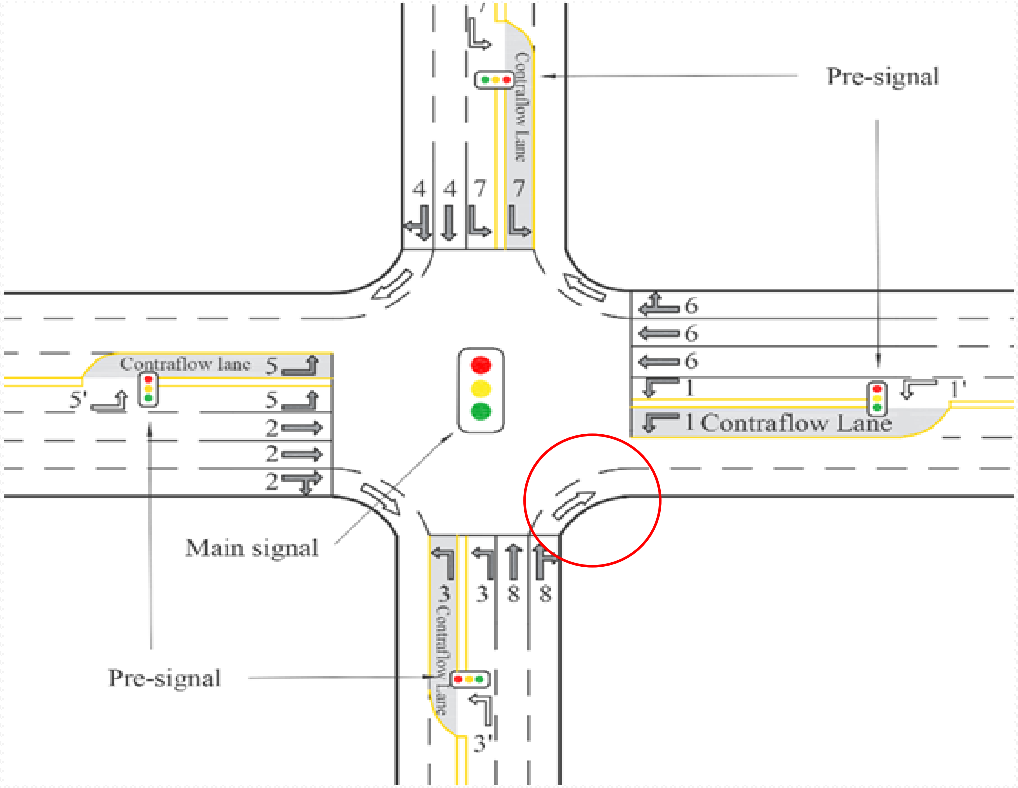
Geometric Design Requirements

- Enough received lanes for the left-turners



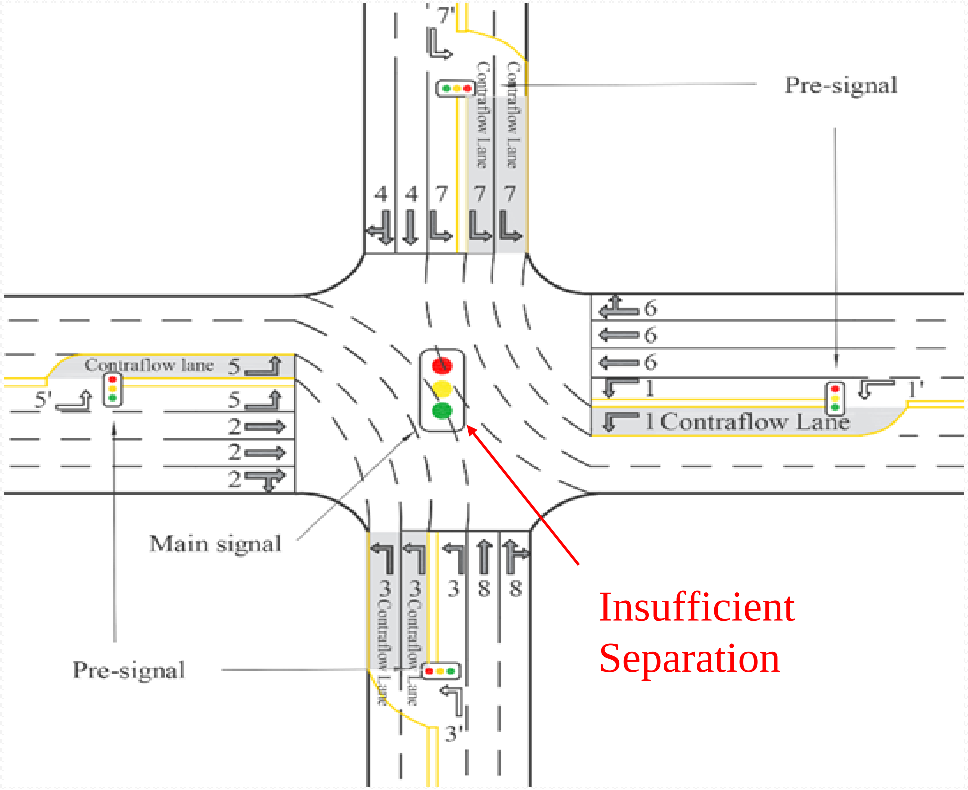
Geometric Design Requirements (Cont.)

- Pavement channelization markings for Right turners



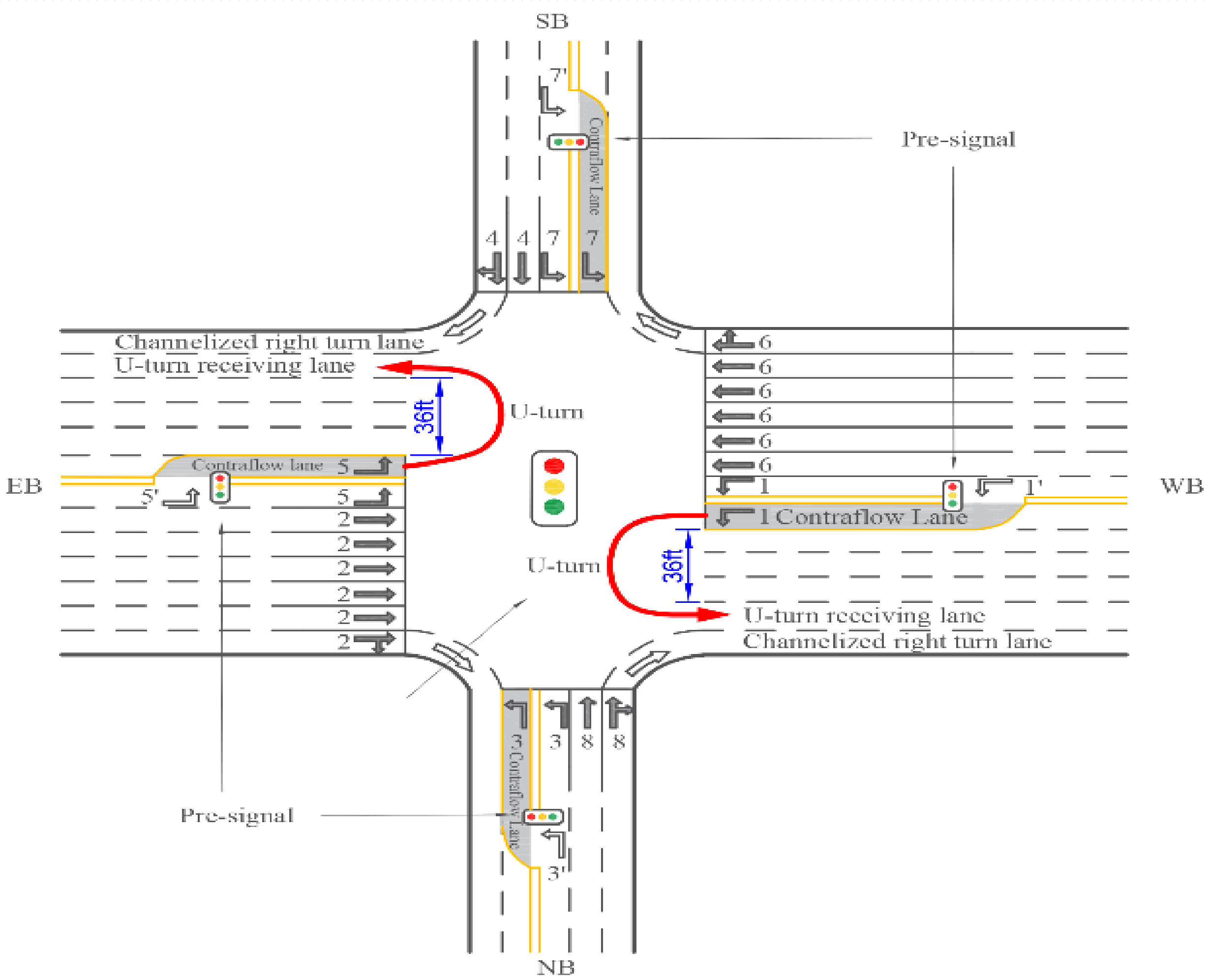
Geometric Design Requirements (Cont.)

- Number of CLLs per approach



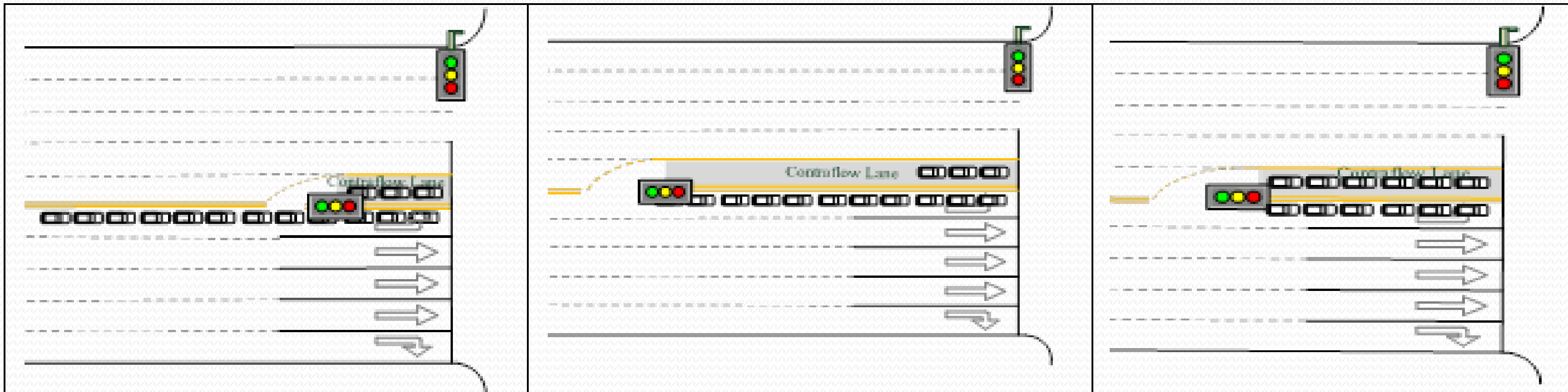
Geometric Design Requirements (Cont.)

- U-turn at CLL intersections should be prohibited



Geometric Design Requirements (Cont.)

- Appropriate length of the CLL

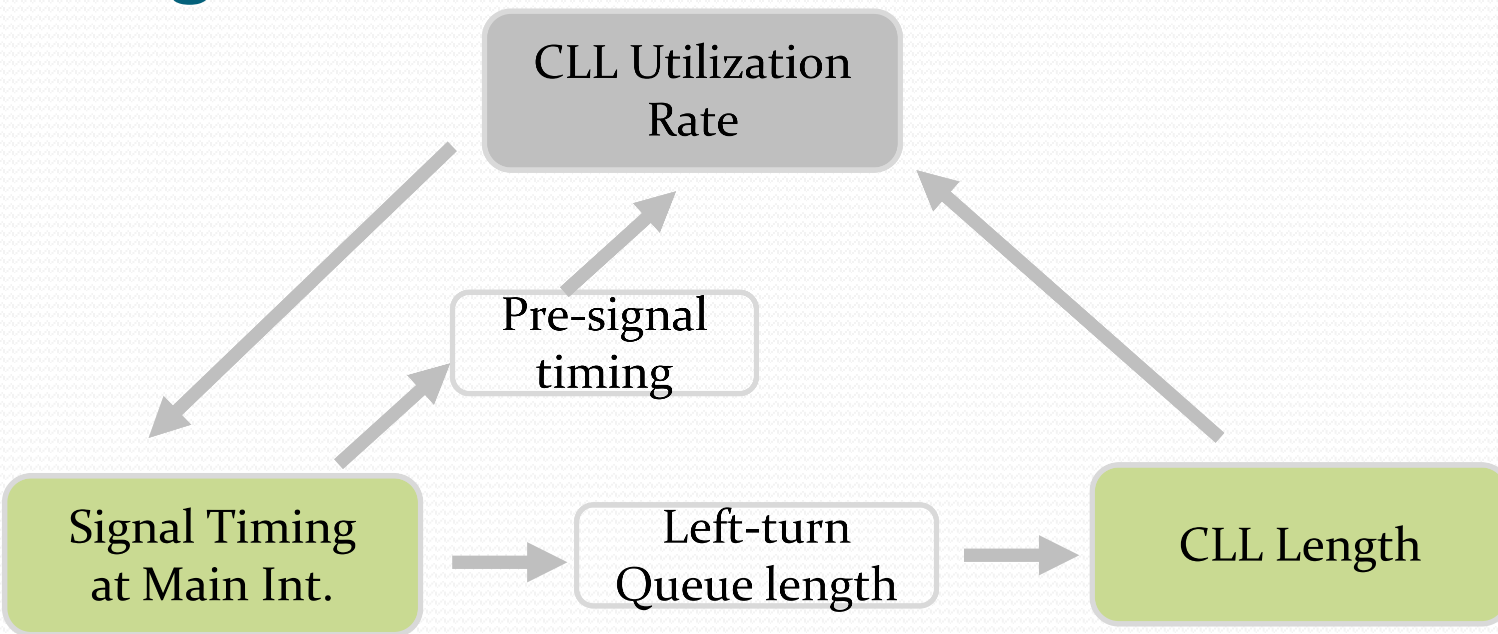


a. *Too short* ***b.*** *Too long* ***c.*** *Appropriate length*

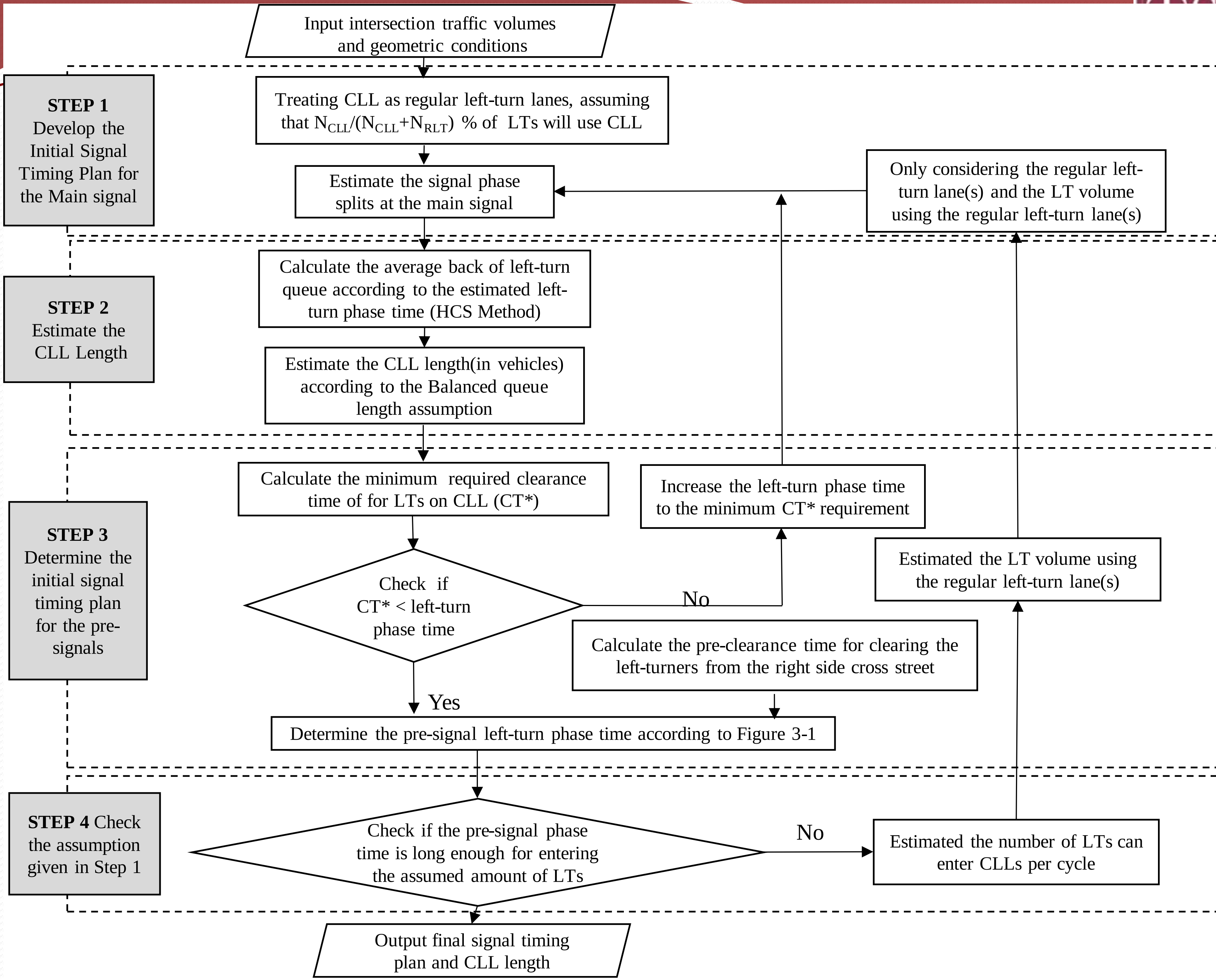
$$L_{CLL} = \frac{Q_{LT}}{N_{CLL}+N_{RLT}} * S_{pc}$$

Q_{LT} is the total left-turn queue backup length.
N_{RLT} is the number of conventional LTLs.
N_{CLL} is the number of CLLs; and
S_{pc} is the average vehicle storage length

Key Deign Elements: Signal Timing and the CLL Length



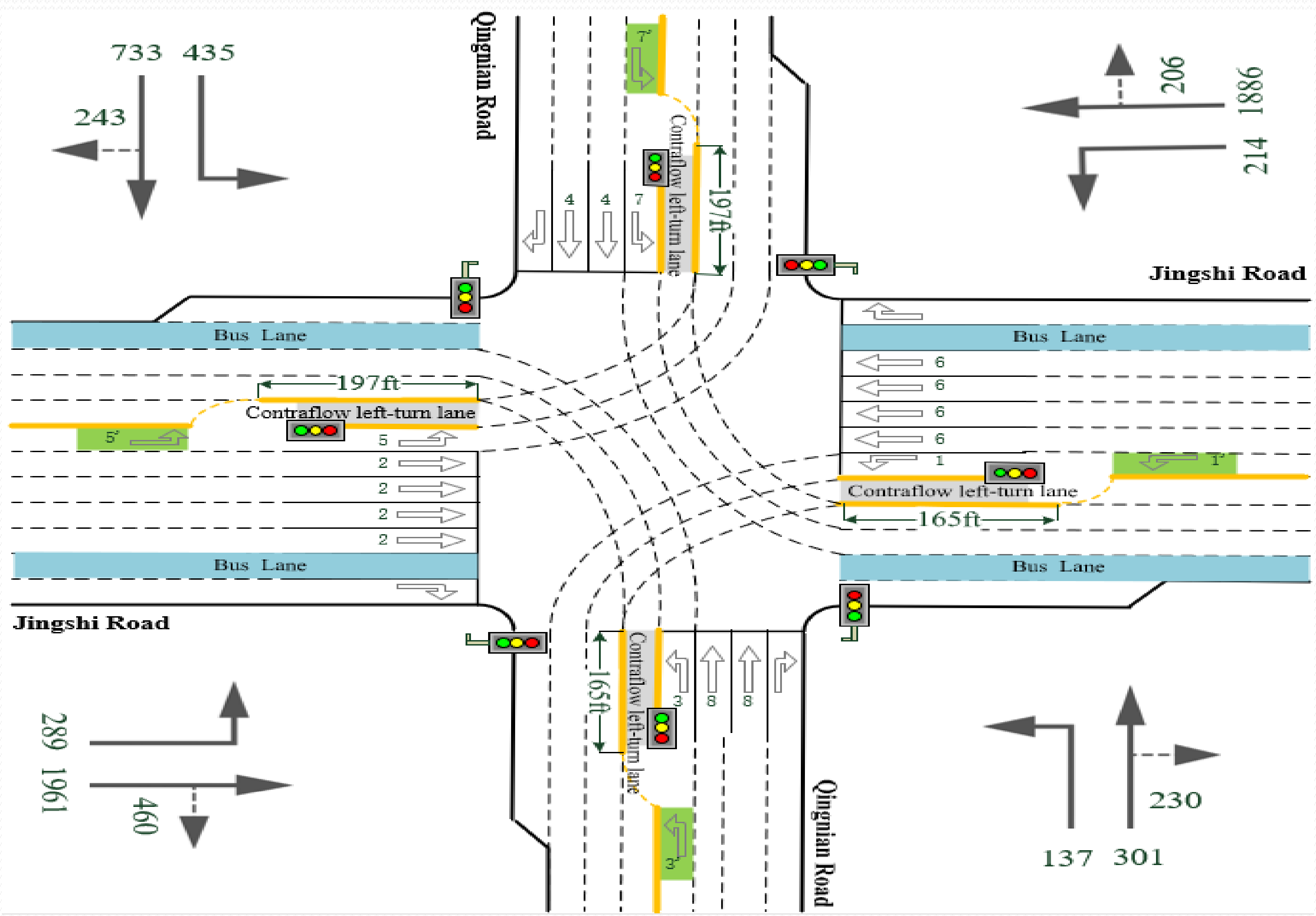
Guo, R., Liu, J., Zhao, Q., & Qi, Y. (2021). Signal timing and geometric design at contraflow left-turn lane intersections. *International Journal of Transportation Science and Technology*.


Input intersection traffic volumes and geometric conditions
STEP 1 Develop the Initial Signal Timing Plan for the Main signal
Treating CLL as regular left-turn lanes, assuming that $N_{CLL}/(N_{CLL}+N_{RLT})$ % of LTs will use CLL
Estimate the signal phase splits at the main signal
Only considering the regular left-turn lane(s) and the LT volume using the regular left-turn lane(s)
STEP 2 Estimate the CLL Length
Calculate the average back of left-turn queue according to the estimated left-turn phase time (HCS Method)
Estimate the CLL length(in vehicles) according to the Balanced queue length assumption
STEP 3 Determine the initial signal timing plan for the pre-signals
Calculate the minimum required clearance time of for LTs on CLL (CT*)
Increase the left-turn phase time to the minimum CT* requirement
Estimated the LT volume using the regular left-turn lane(s)
Check if CT* < left-turn phase time
No
Calculate the pre-clearance time for clearing the left-turners from the right side cross street
Yes
Determine the pre-signal left-turn phase time according to Figure 3-1
STEP 4 Check the assumption given in Step 1
Check if the pre-signal phase time is long enough for entering the assumed amount of LTs
No
Estimated the number of LTs can enter CLLs per cycle
Output final signal timing plan and CLL length

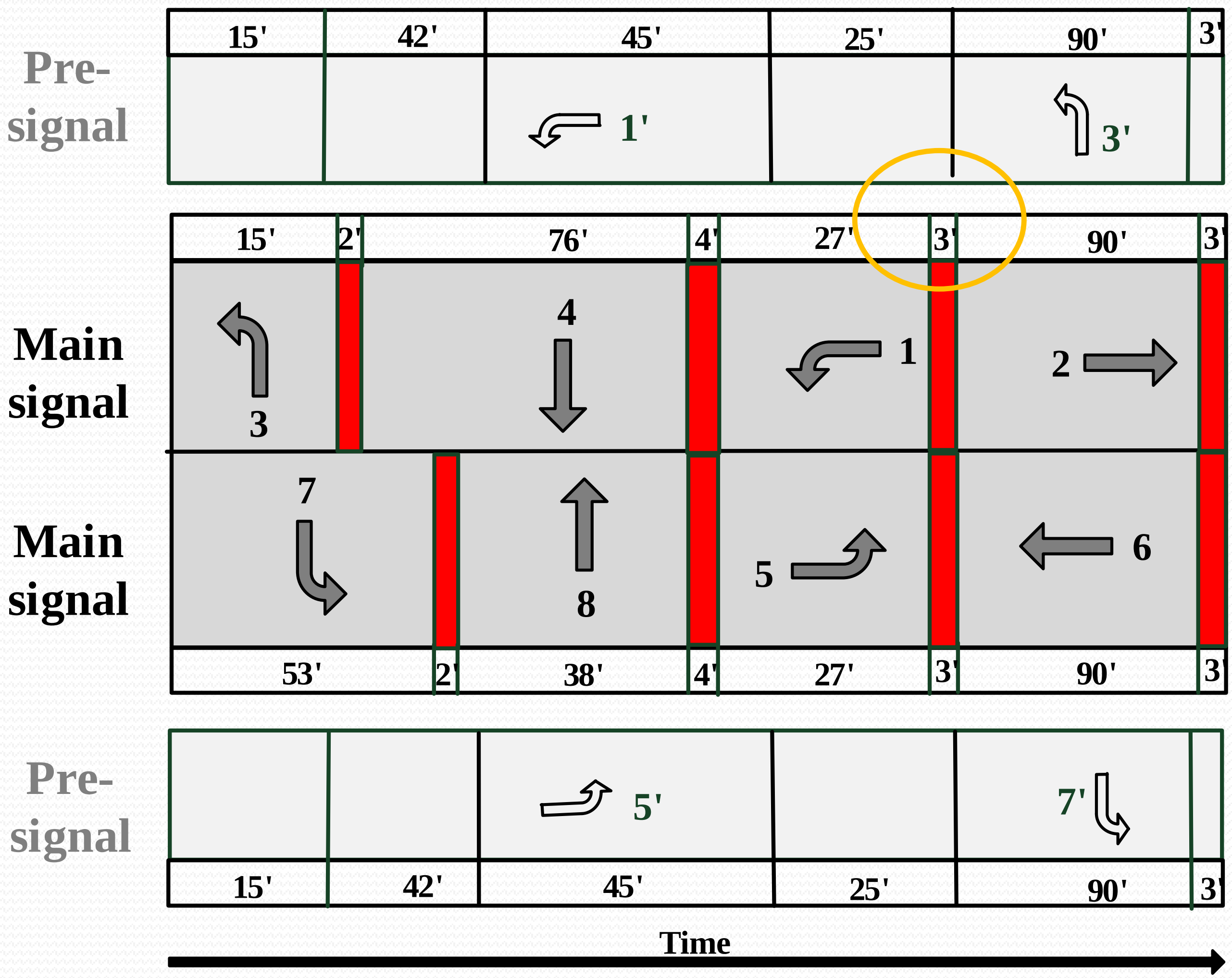
A Case study I

To redesign the signal timing and CLL lengths for a existing CLL intersection by using the proposed method

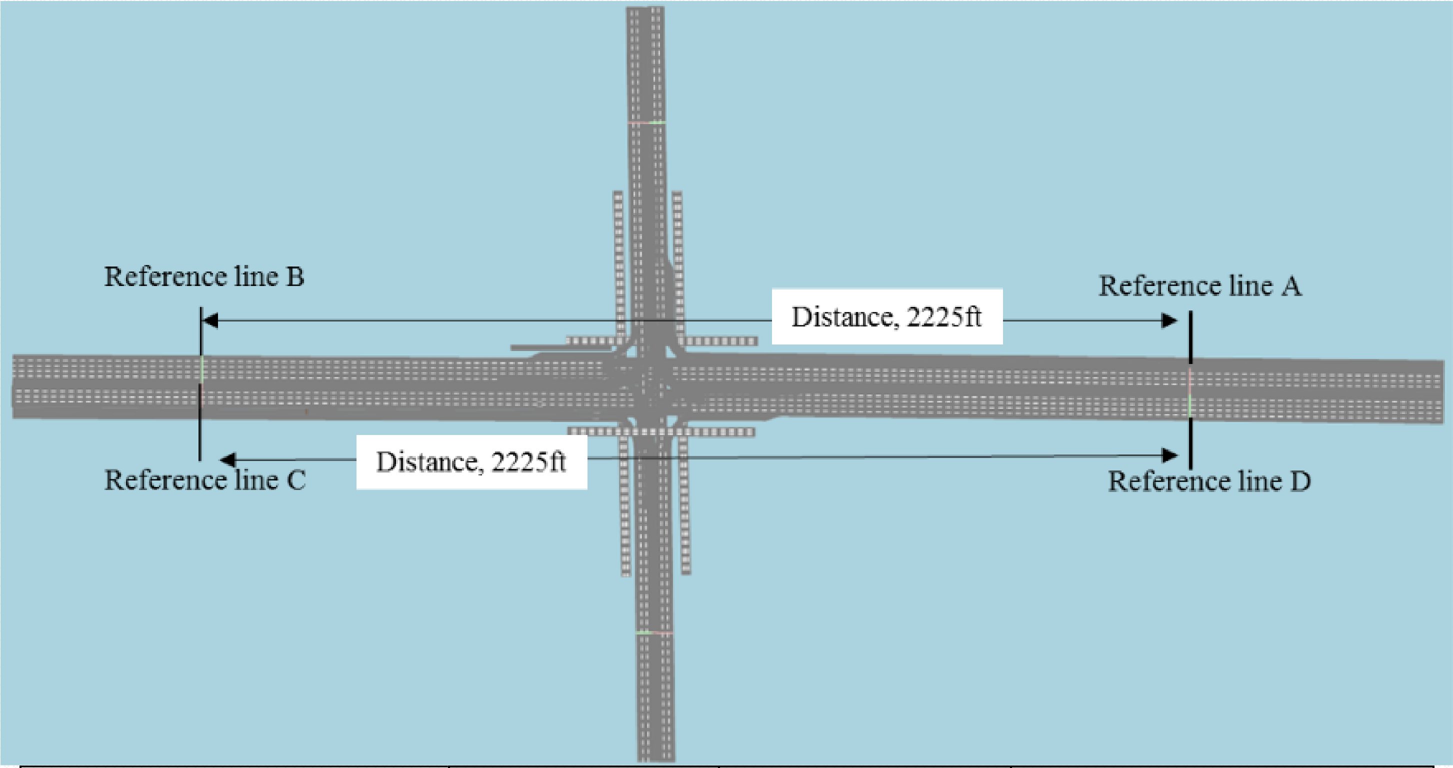
Intersection Layout and Traffic Conditions



Existing Signal Timing Plan

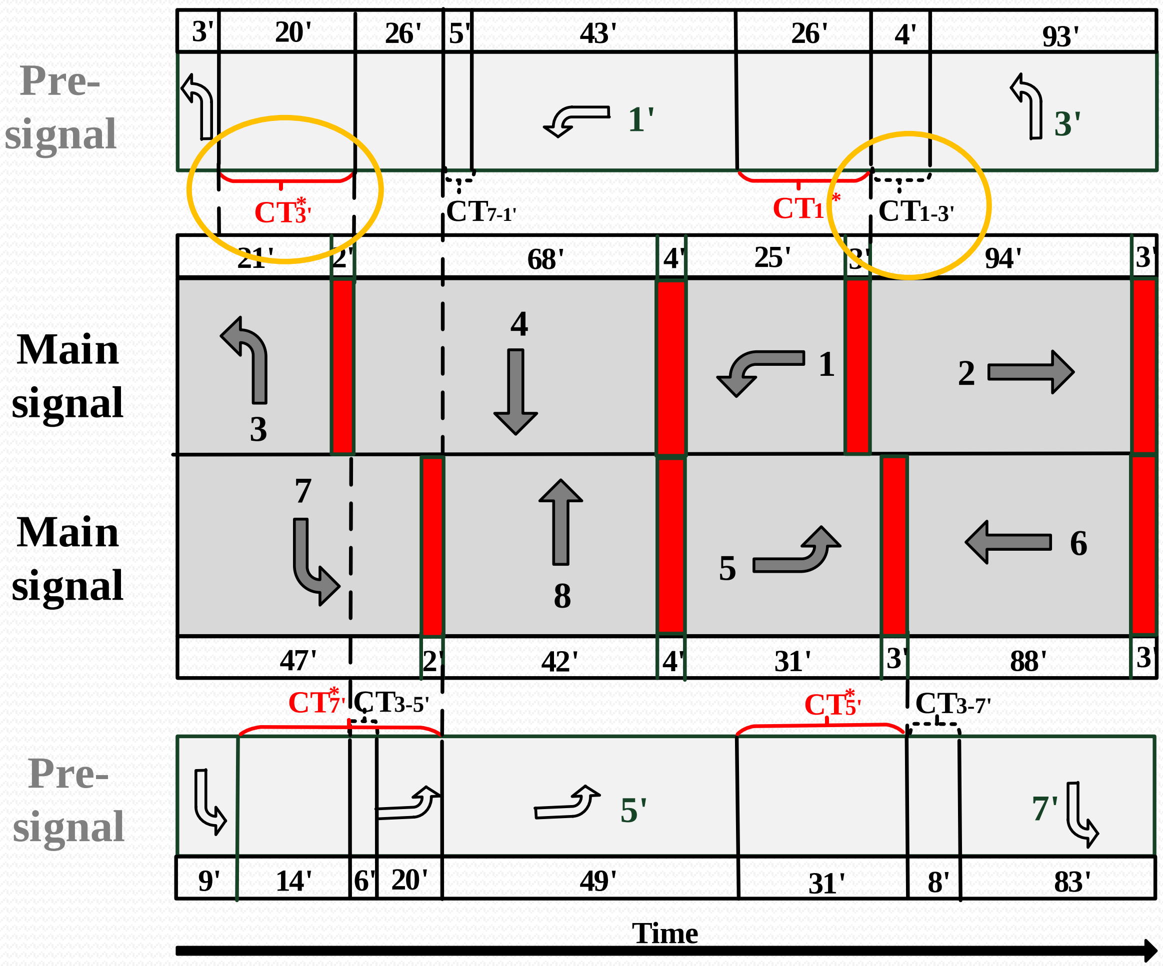


Traffic Simulation



	Observed (s)	Simulated (s)	Relative error (%)
Travel time from C to D	178.7	171.1	-4.3%
Travel time from A to B	135.2	129.3	-4.4%

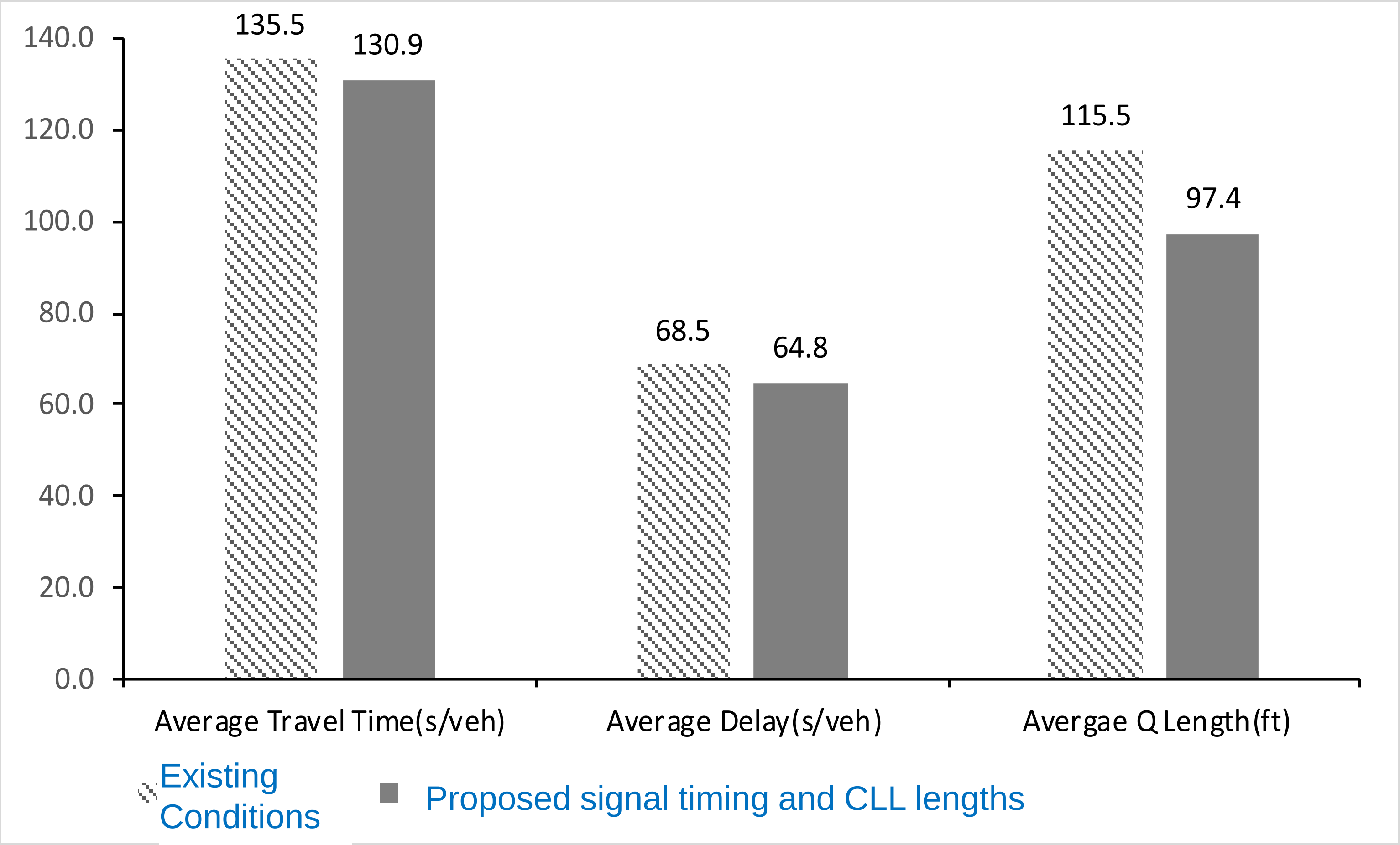
Developed Signal Timing Plan



Estimated CLL length

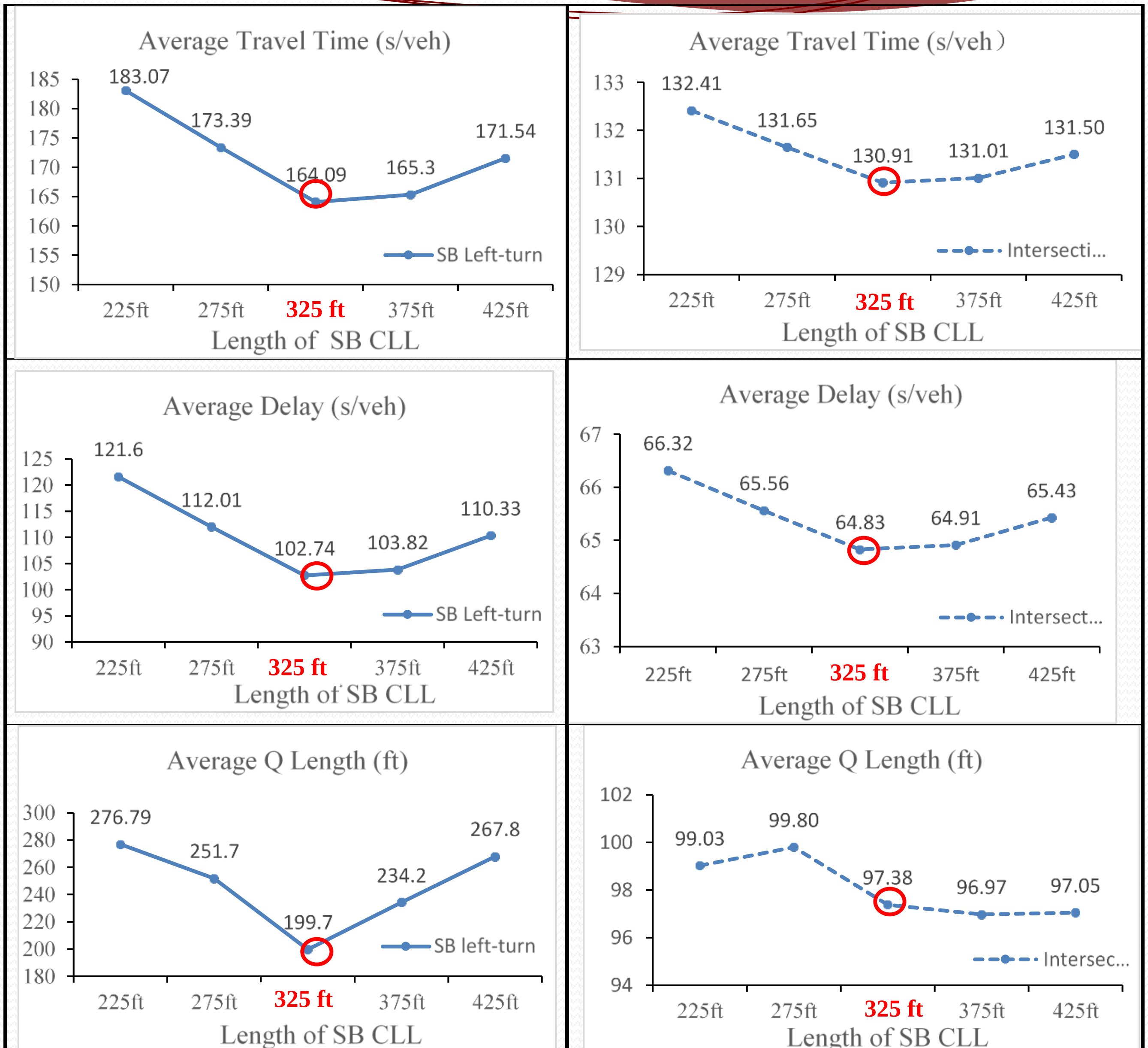
- Estimated CLL length of WB is 175ft (the exiting length is 165ft)
- Estimated CLL length of EB is 225ft. (the exiting length is 197ft)
- Estimated CLL length of NB is 125ft (the exiting length is 165ft)
- **Estimated CLL length of SB is 325ft (the exiting length is 197ft)**

Comparison of Operational Performance



Estimated CLL length of **SB** is **325ft** (the exiting length is 197ft)

Increase it from **225 ft to 425** in 50 ft increments (5 scenarios)



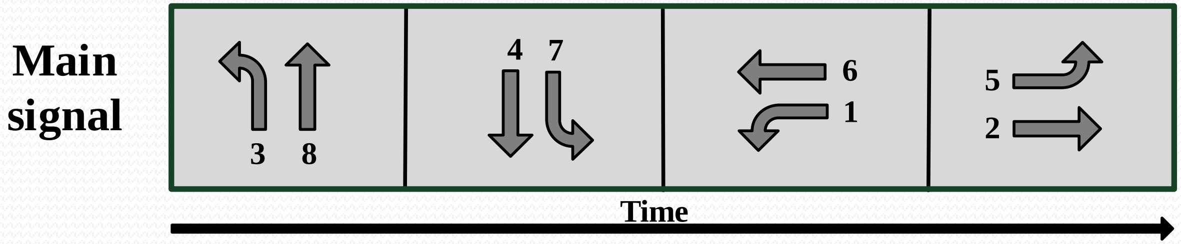
(a) Operational Performance for the EB Left-turn (b) Operational Performance for the Entire Intersection

FINDINGS

- The redesigned CLL intersection outperforms the existing CLL intersection in terms of the average traffic delay, average vehicle travel time, and average queue length
- The redesign signal timing considered both types of clearance times (pre-clearance and end-clearance time) in the CLL signal timing design. Thus, it will reduce the risk associate with the use of CLLs.

Question: Can Contraflow Left-turn Lanes be used at Signalized Intersections with Split Phasing ?

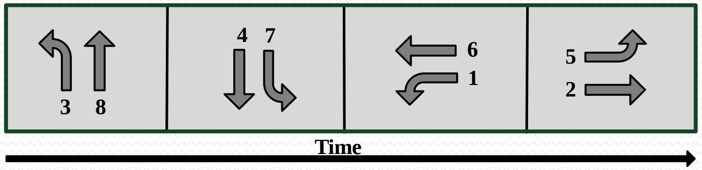
- **Split phasing:** assign the right-of-way to all movements of a particular approach, followed by all of the movements of the opposing approach



Split Phasing

Split Phasing

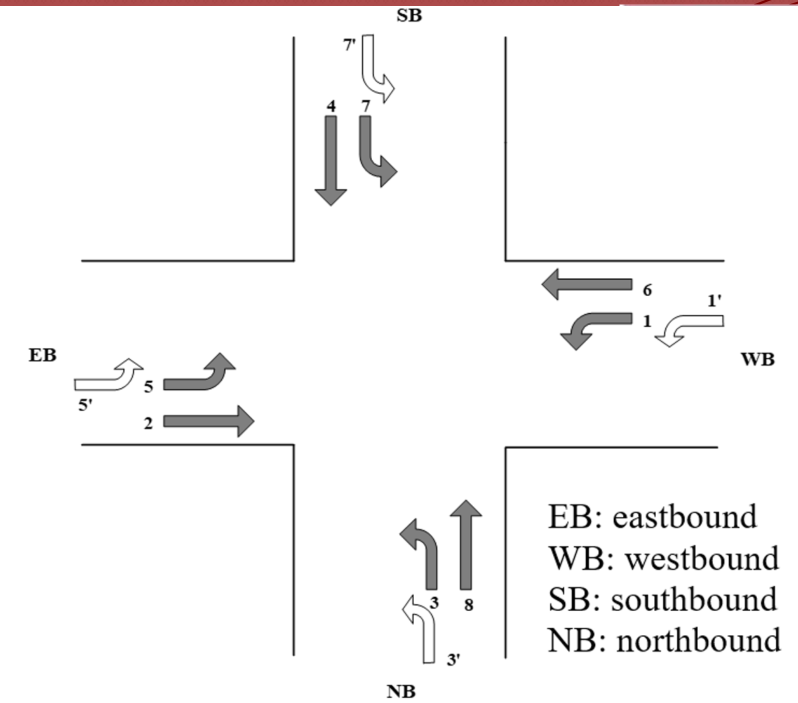
Main signal

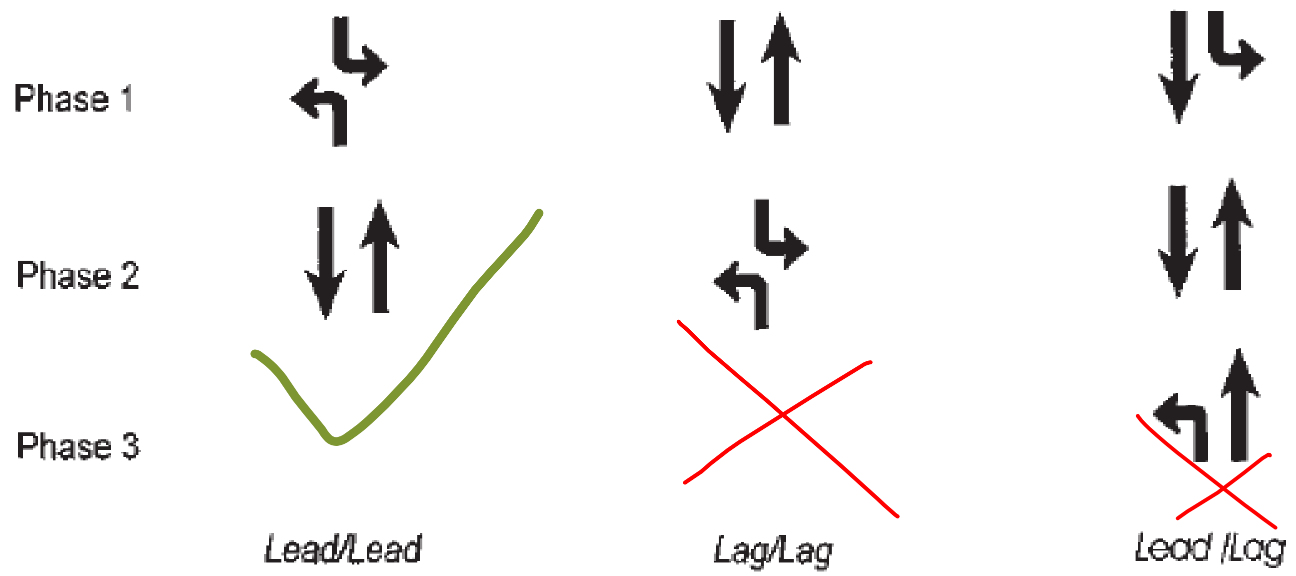


- Split phasing is **necessary** under certain intersection geometry conditions, such as
  - No space for an exclusive left-turn lane, but have heavy left-turn traffic
  - The opposing left-turn paths overlap because of intersection geometry layout
- Split phasing is **recommended** under certain intersection traffic conditions
  - Balanced left-turn and through traffic **from same approach** (left-turn vehicles/lane are approximate to through vehicles/lane)
  - Unbalanced total traffic **from the two opposing approaches**

Signal timing requirements

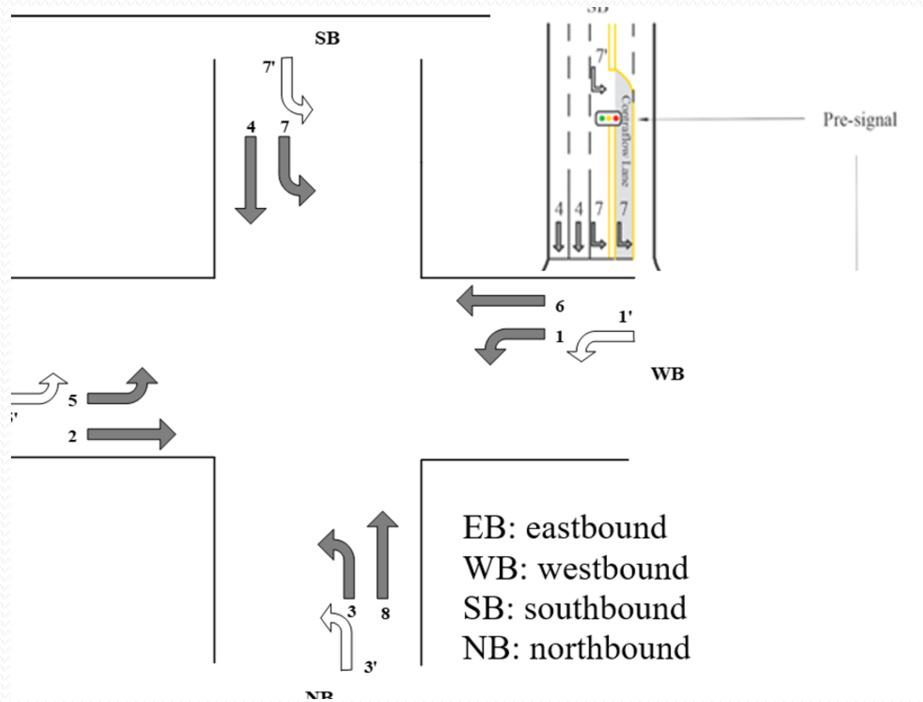
- **lead-lead protected LT only** & It can't work with the lagging left-turn phase (Limitation):



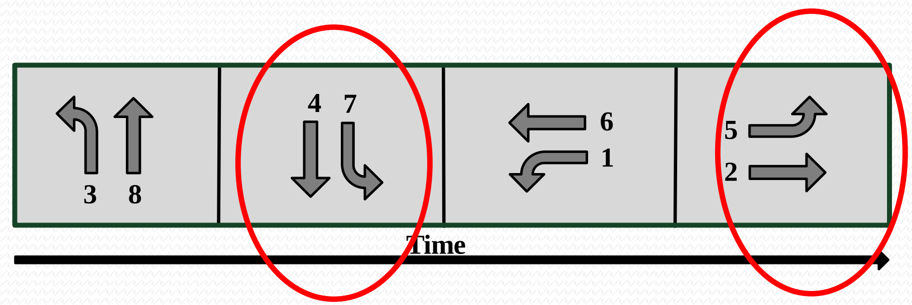


Problems

- CLL design cannot be directly used at the intersections with split phasing

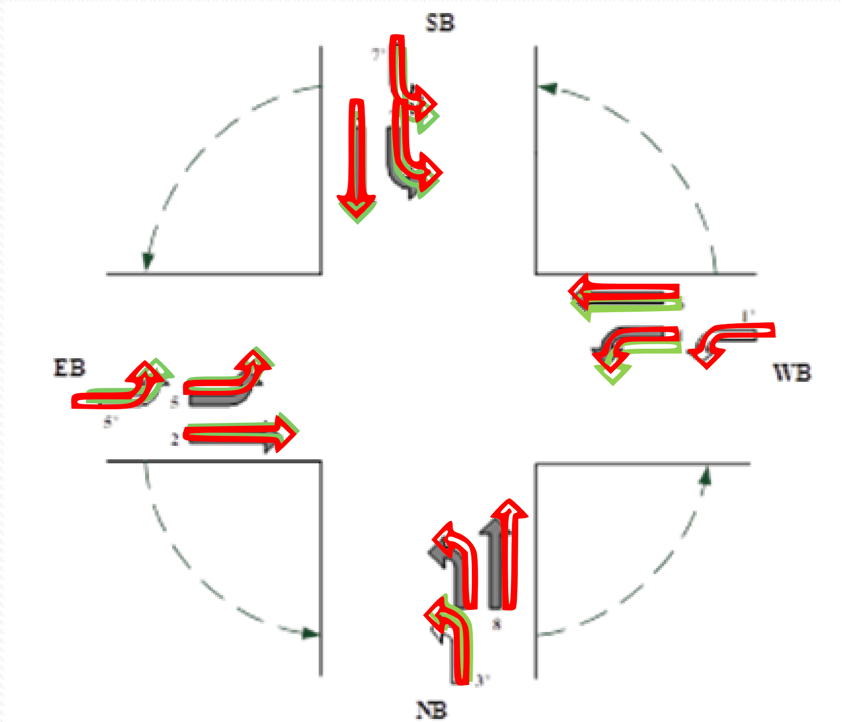


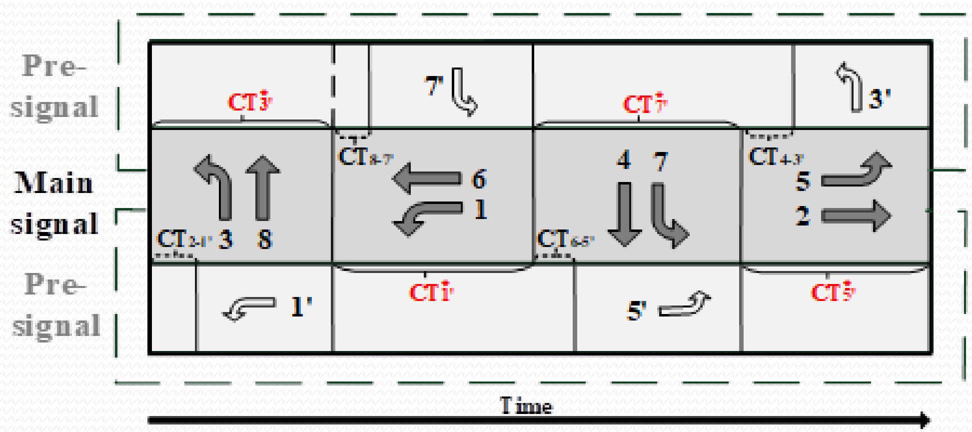
Main signal



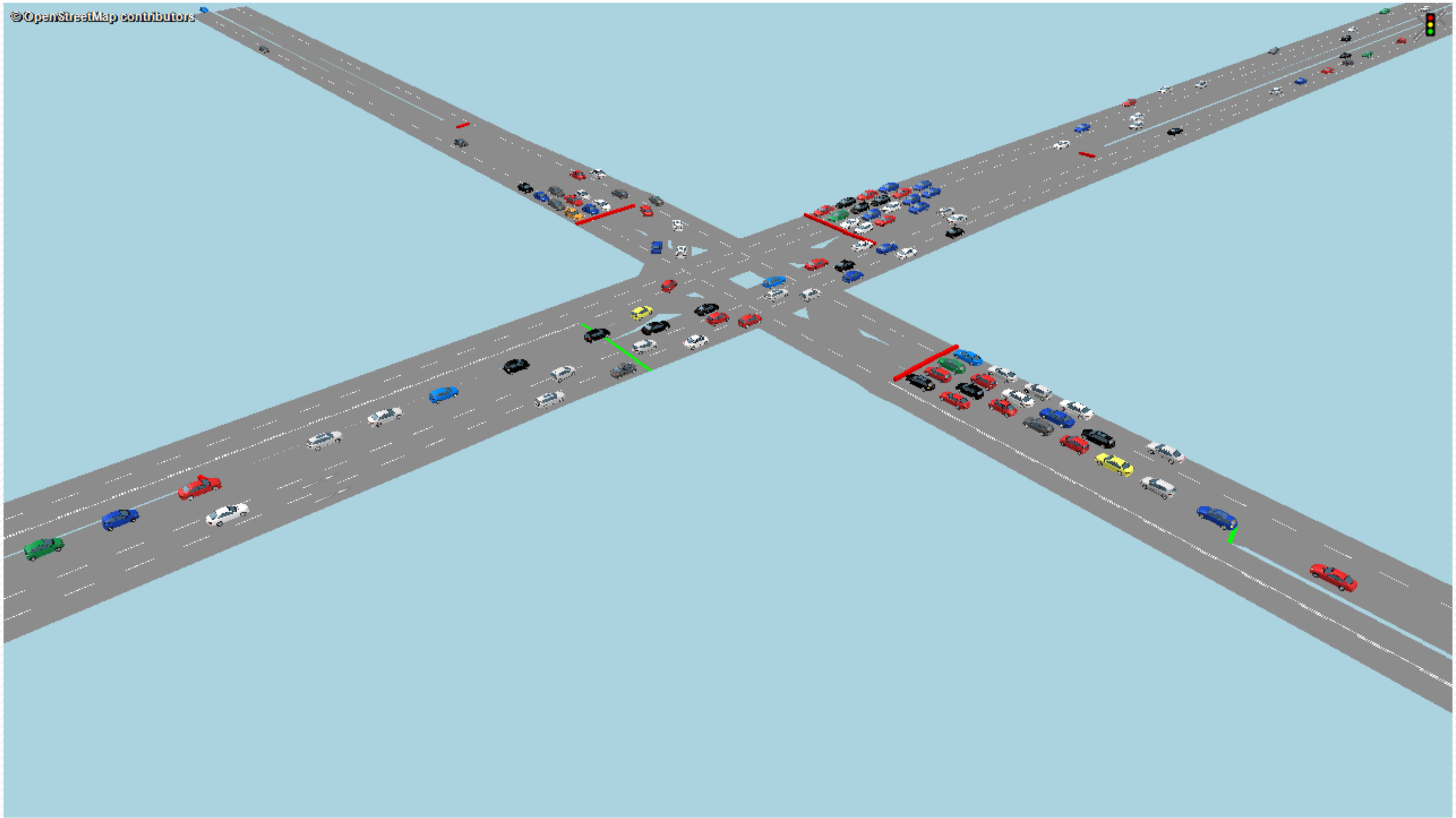
Basic Idea

- an innovative signal timing strategy called Counterclockwise Split Phasing (CSP) signal timing

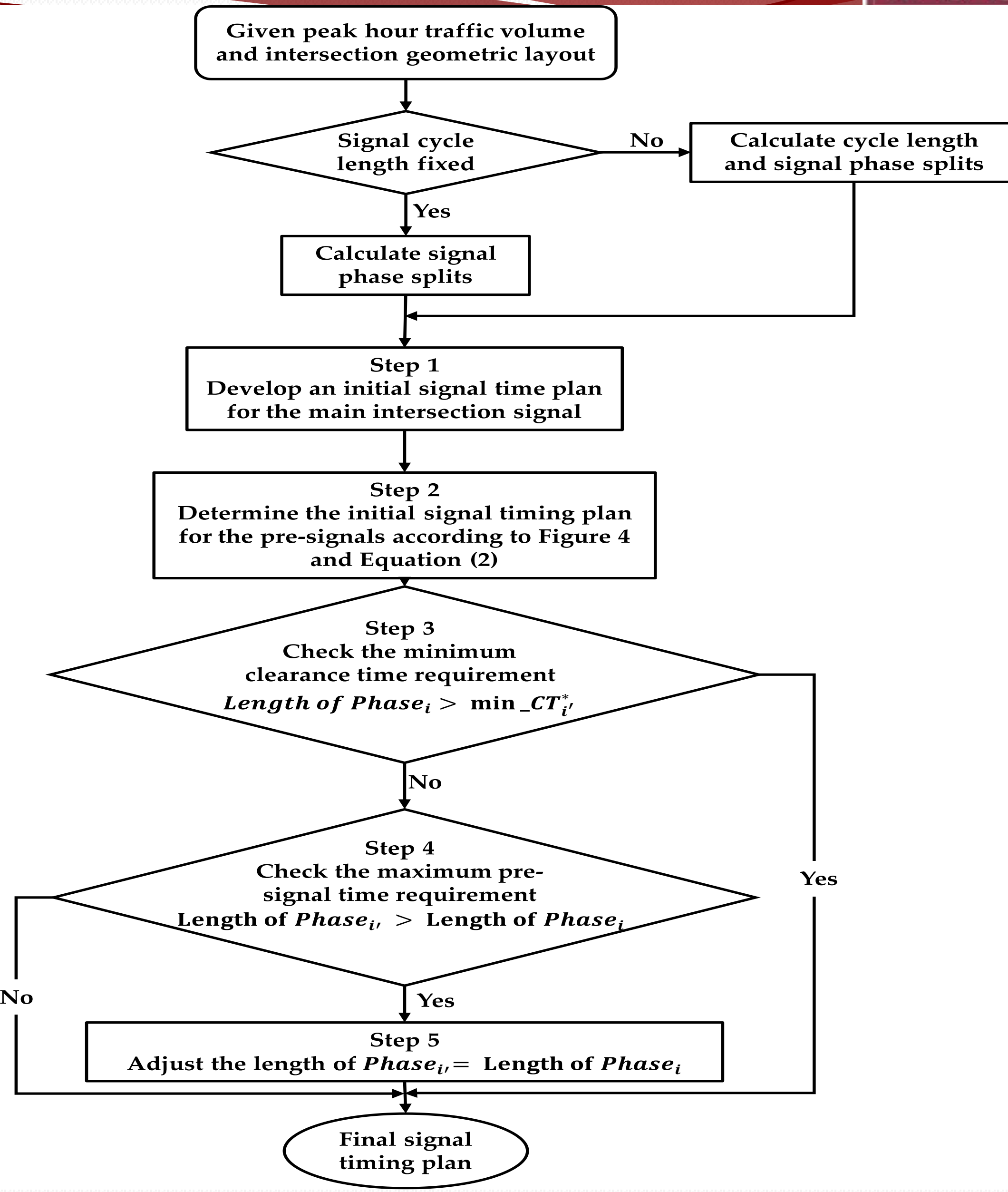




Counterclockwise Split Phasing (CSP) signal timing



Procedure for Developing the CSP Signal Time Plan for a CLL Intersection W Slit Phasing

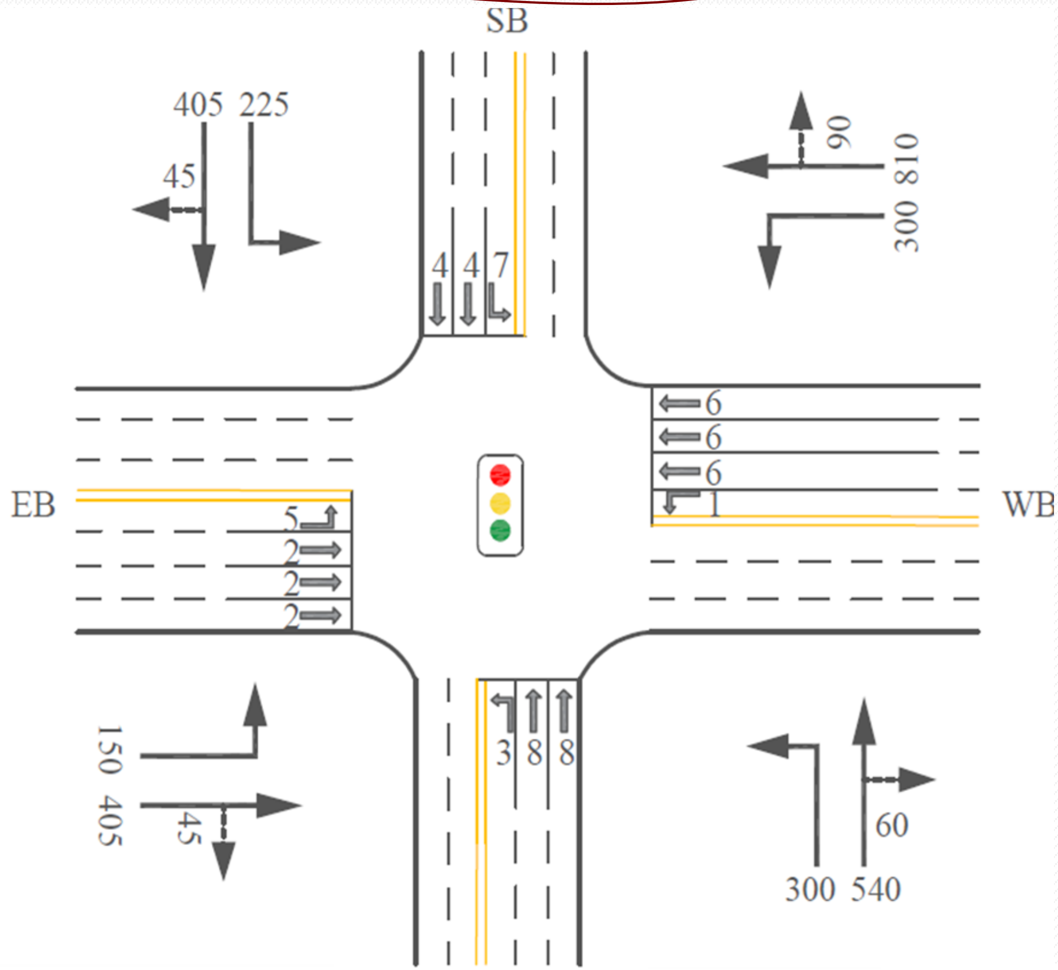


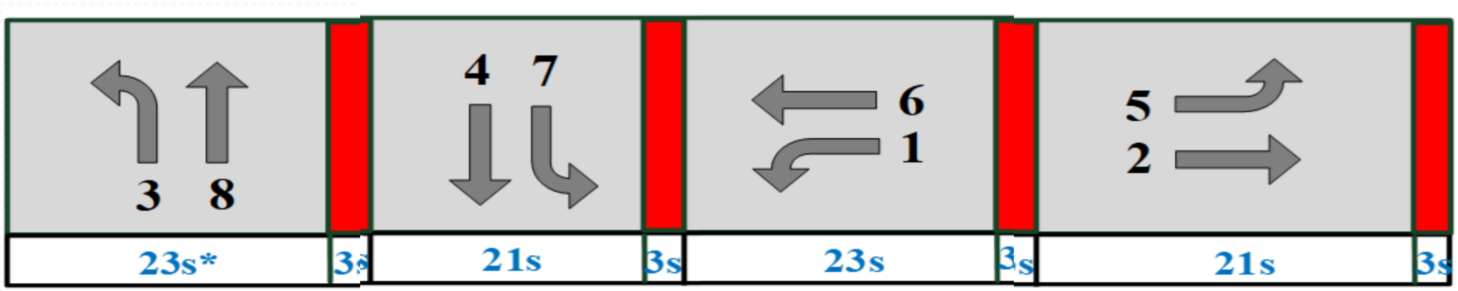
Guo, R., Liu, J., & Qi, Y. (2021). An Innovative Signal Timing Strategy for Implementing Contraflow Left-Turn Lanes at Signalized Intersections with Split Phasing. *Sustainability*, *13*(11), 6307.

A Case study II

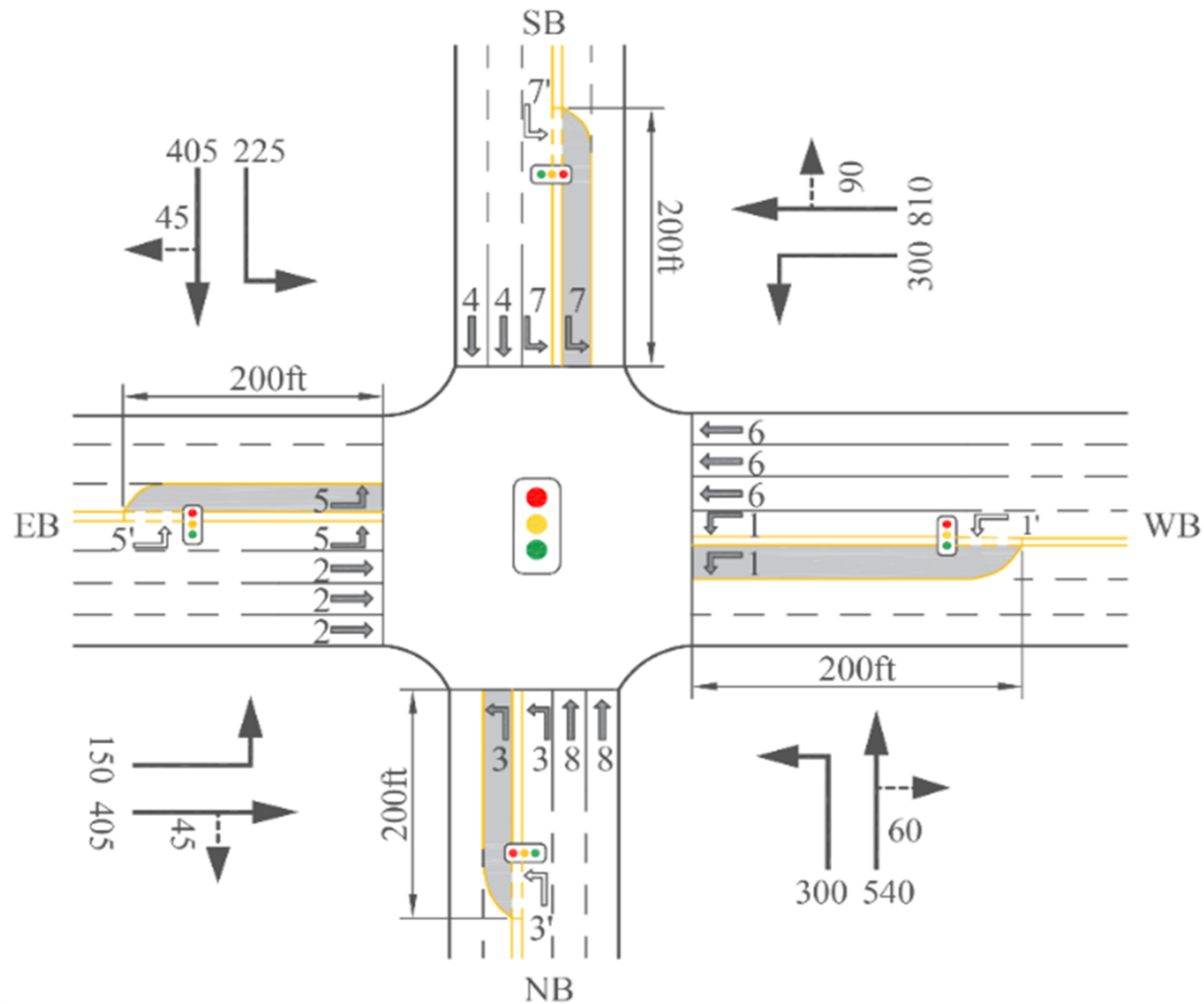
To demonstrate the benefits of using the proposed the CSP signal timing at a **hypothetical intersection** where split phasing is recommended

Intersection Layout, Traffic Conditions and signal timing (base Model)



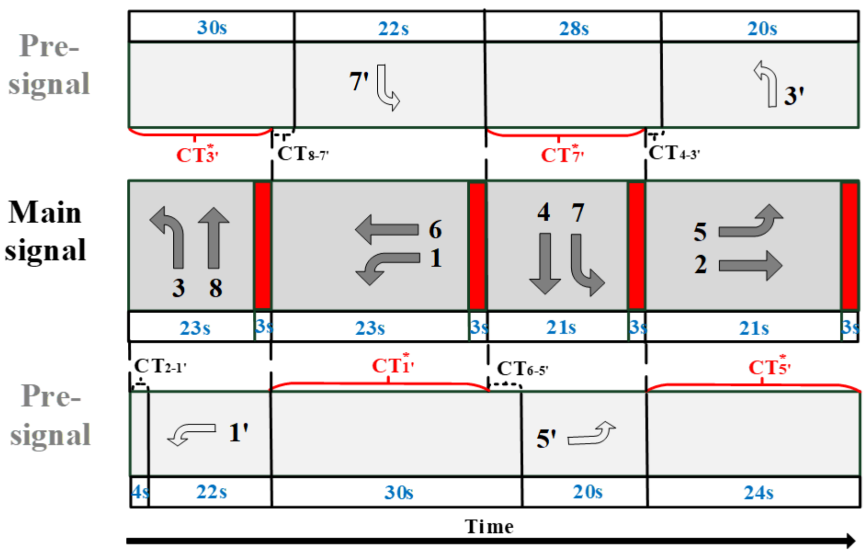


Hypothetical intersection With CLL design

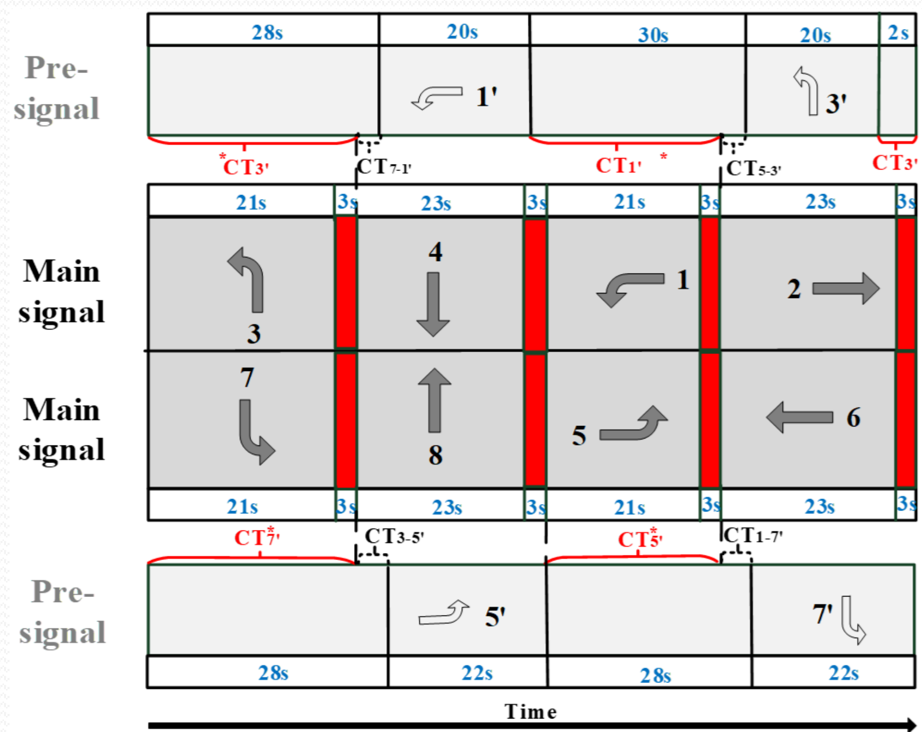


Hypothetical intersection With CLL design

Option A: Using the proposed CSP signal timing strategy



Option B: Using the conventional lead-lead protected left-turn phases for the CLL design



Traffic Simulation in VISSIM

- **Simulation Scenarios**

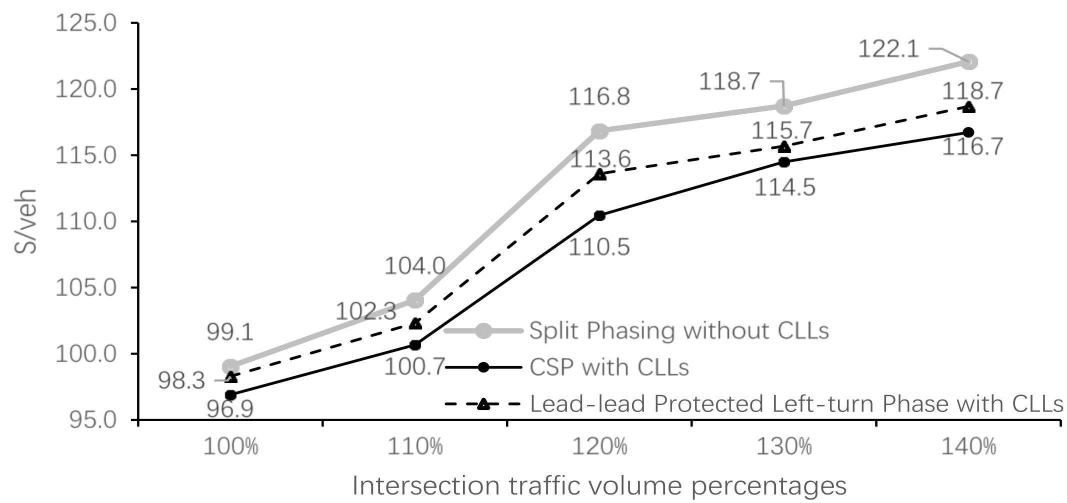
A. Scenarios with varied intersection traffic volume

B. Scenarios with varied left-turn traffic volume

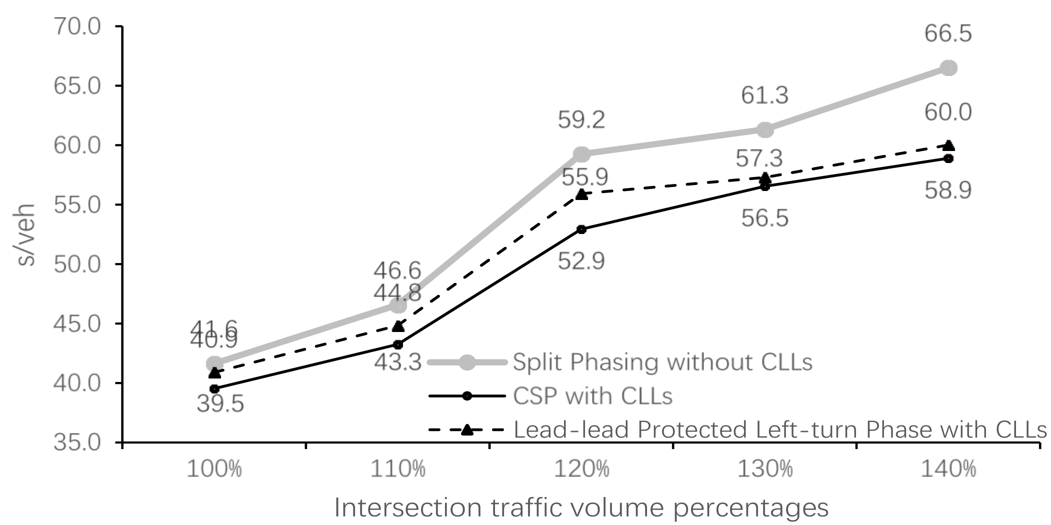
C. Scenarios with varied levels of unbalanced traffic volume conditions

Results I

- Scenarios with <u>varied levels of intersection traffic volume</u>



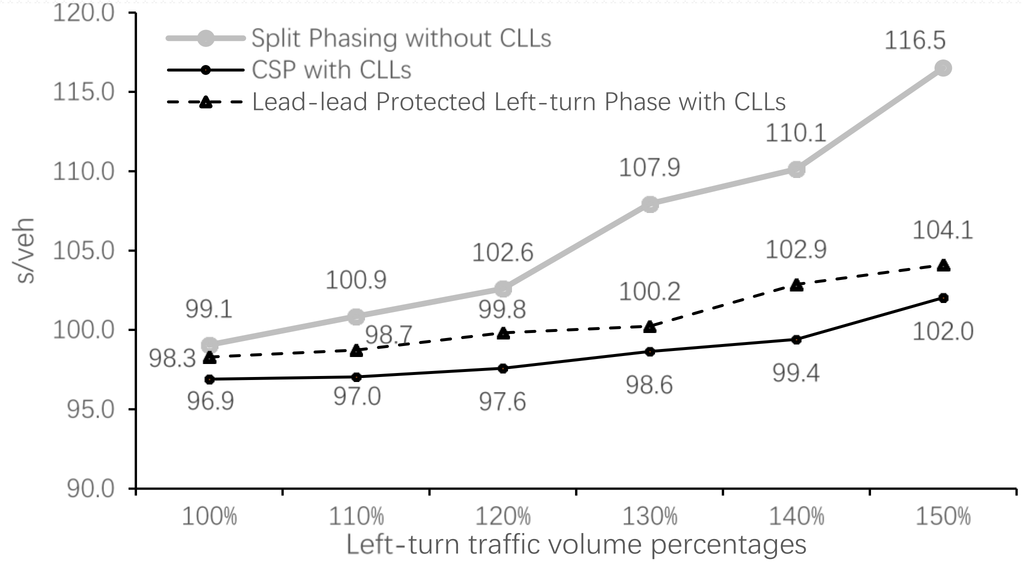
a) Average Travel Time



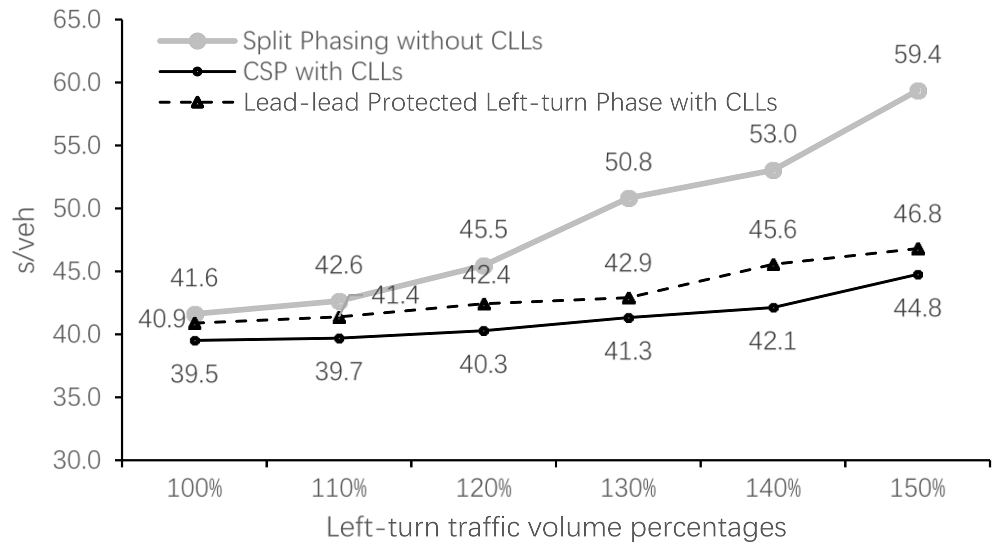
b) *Average Delay*

Results II

- Scenarios with <u>varied levels of left-turn traffic volume</u>



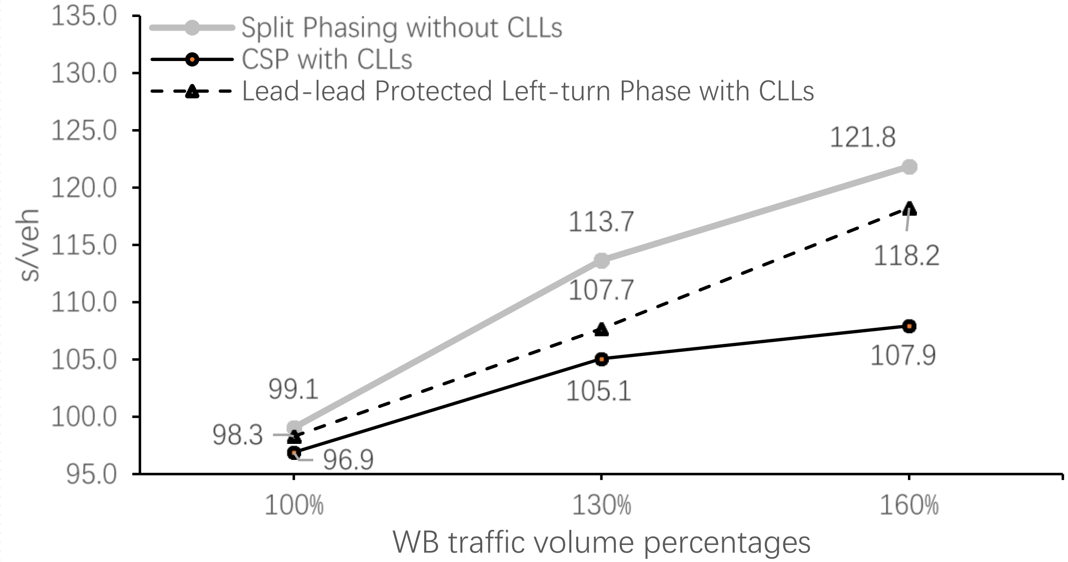
a) Average Travel Time



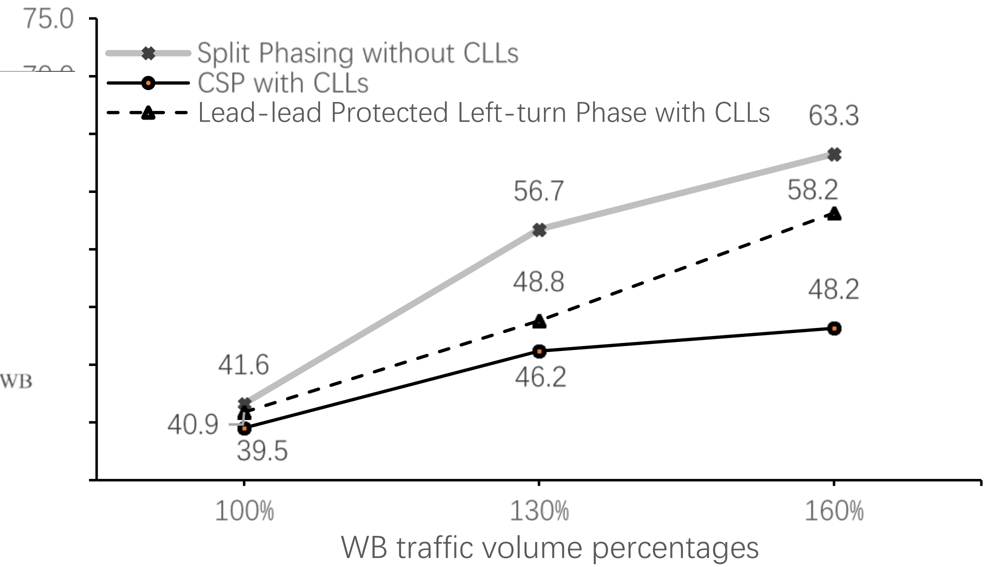
b) Average Delay

Results III

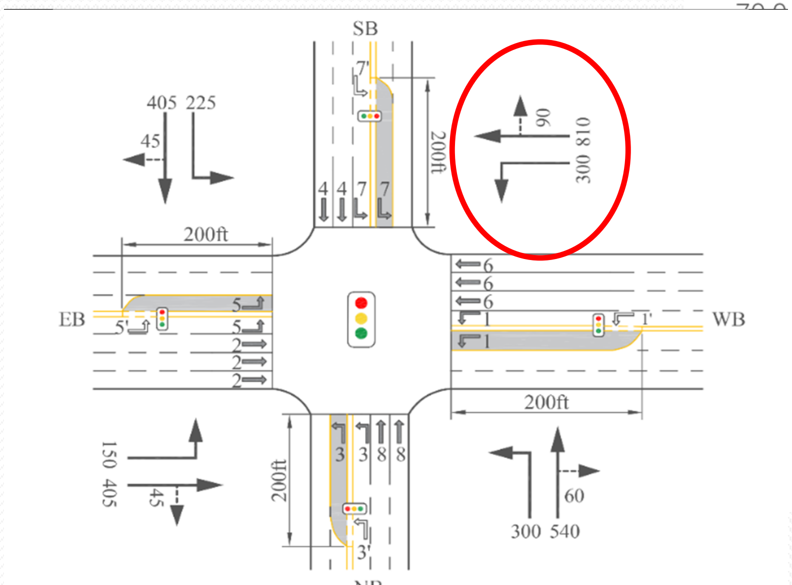
- Scenarios with <u>varied levels of unbalanced traffic volume conditions (increase the WB traffic from 100% to 160%)</u>



a) **Average Travel Time**



b) **Average Delay**



Findings

- Use of the proposed CSP signal timing can combine the advantages of the split phasing and the CLL design, thereby achieving more operational and safety benefits at the intersections where split phasing is recommended or required.

Conclusions and Recommendations

- CLL design can reduce the traffic congestion at the signalized intersections with heavy left turn traffic
- It should be carefully design by considering all the design requirements, especially the signal time requirements to reduce the risk associate with the use of CLLs
- CSP signal timing is good solution for using CLL design at the intersections where split phasing is needed
- Adequate pavement marks and traffic signs are important for this new design.

Questions?

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