SignalAPI User’s Guide

CONTACT INFORMATION

Further Details in https://github.com/xzhou99/SignalAPI

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1 Introduction

The goal of this open-source package is to develop a light-weight computational engine to input and optimize signal control timing data, and analyze the effectiveness of signal control strategies. This SignalAPI engine is written in C++ based on an QEM spreadsheet tool written by Prof. Milan Zlatkovic (https://github.com/milan1981/Sigma-X).

Meanwhile, users can utilize NeXTA-GMNS (https://github.com/xzhou99/NeXTA-GMNS) as a network visualization tool to display related optimization results.

2 Steps for using SignalAPI

2.1 Download software packages

Before using SignalAPI executables, the users are strongly recommended to use and understand the internal logic of Sigma-X. https://github.com/milan1981/Sigma-X

The latest software release can be downloaded at https://github.com/xzhou99/SignalAPI. Table 1. illustrates the contents of different folders in the package.

Table 1. Folders of SignalAPI package

Github Folder Name	**Contents**
Src	source code of SignalAPI
Release	Executable of SignalAPI.exe in Windows
Doc	User's guide and other documentations for SignalAPI
Dataset	1. Steps for Signal Control.docx 2. GMNS based network csv files, and additional extension in the **road_link.csv** for additional movement related attributes) 3. Case studies (including 3 cases with QEM Excel file)

2.2 Input Data Preparation

Users should collect the basic information for signal control, including intersection id, movement type, number of lanes, lane type, and volume for each movement.

2.3 Prepare file road_link.csv

Once we have the count data ready for the intersection of interest, please open folder "dataset ->1_signal_intersection_test2" (Fig.1) and locate the csv file "road_link.csv" (Fig.2).

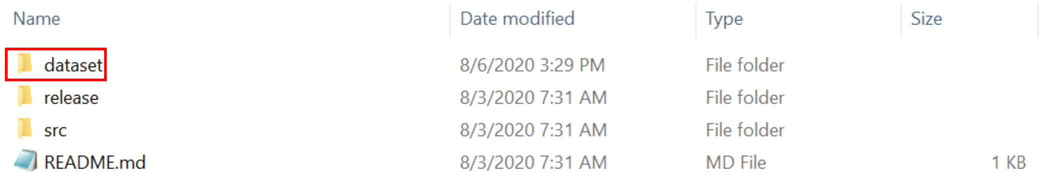


Fig.1 Location of the folder "dataset"

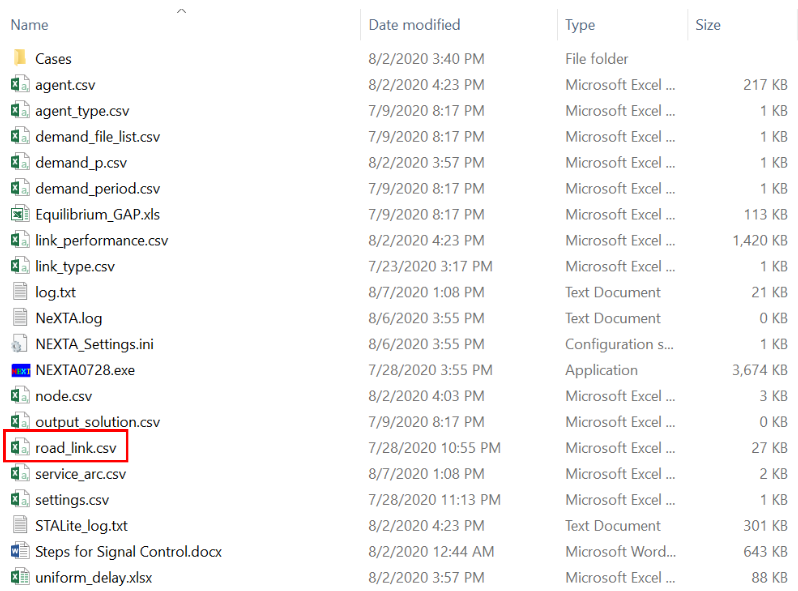


Fig.2 Location of the csv file "road_link.csv"

The basic attributes of the file "road_link.csv" follow the GMNS specification (link here). The additional fields for signal timing optimization are shown in Table 2.

Table 2. List of additional fields for signal timing optimization

Field Name	**Description**
lanes	Number of lanes for a movement
main_node_id	Intersection ID
movement_str	Movement Type
volume	Volume for each movement

An illustrative example of an intersection is shown in Fig.3.

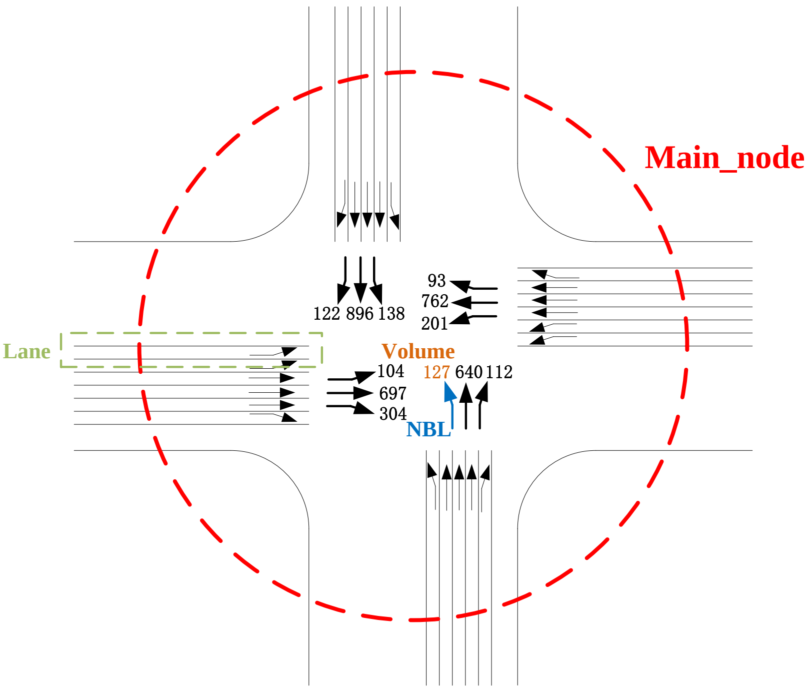


Fig.3 An illustrative example of an intersection

The user can summarize the basic information of the intersection in Table 3.

Table 3. Basic information of the illustrative intersection

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Volume	104	697	304	201	762	93	127	640	112	138	896	122
No. of lanes	2	3	1	2	3	1	1	3	1	1	3	1

2.4 Compile and run SignalAPI in visual C++ environment

Firstly, open the folder “src->Exe_src” and open the C++ project solution file “SignalAPI.sln”, as shown in Fig.4.

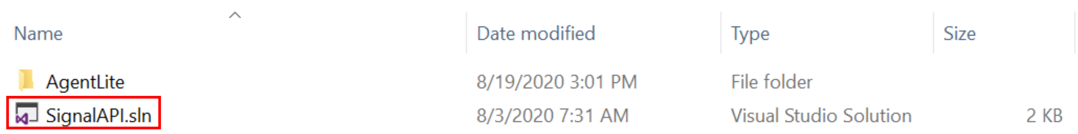


Fig.4 Location of the C++ project solution file

The source code starts with “SignalAPI.cpp”, as shown in Fig.5.

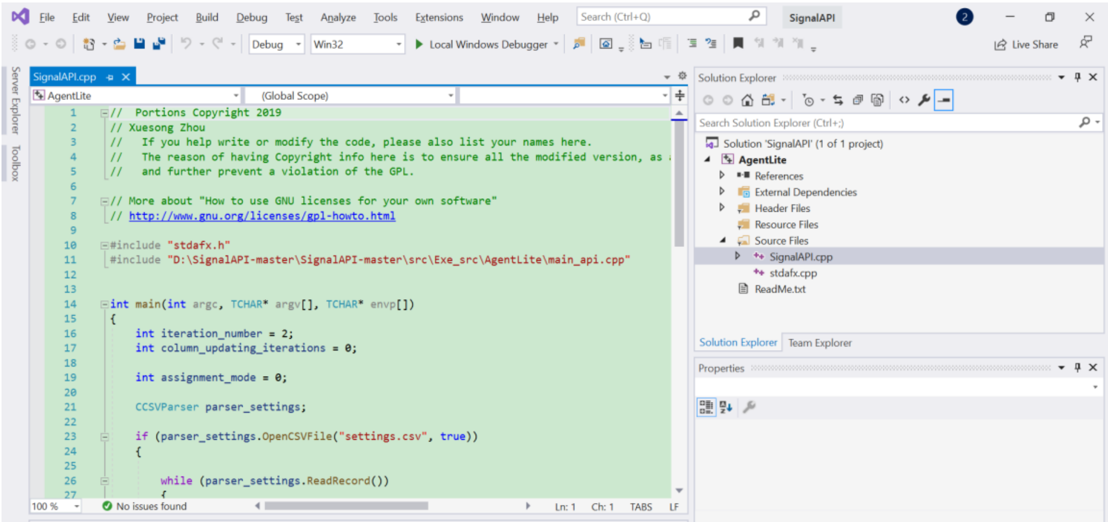


Fig.5 SignalAPI.cpp source code

The mechanism of signal control and the core modeling steps of SignalAPI are implemented in file “main_api.cpp” (Fig.6). To successfully execute the project with a data set, we need to setup the working directory of the data set through “Project”-“AgentLite Attribute”-“Debugging”.

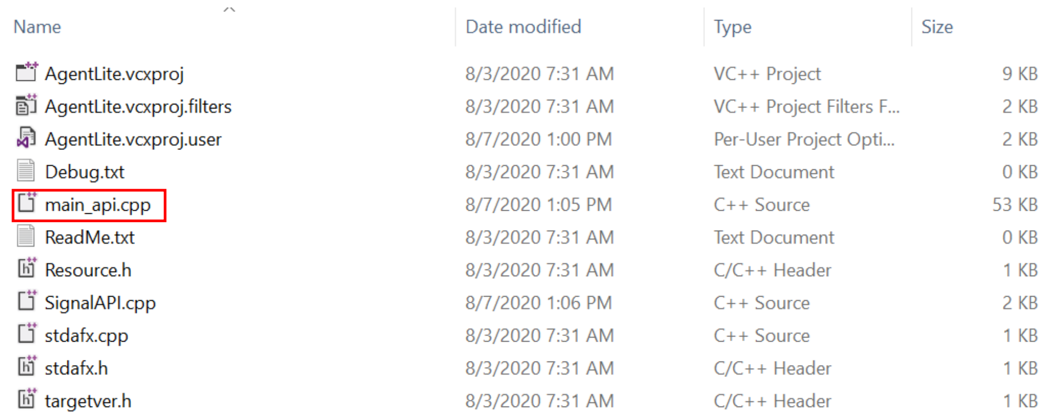
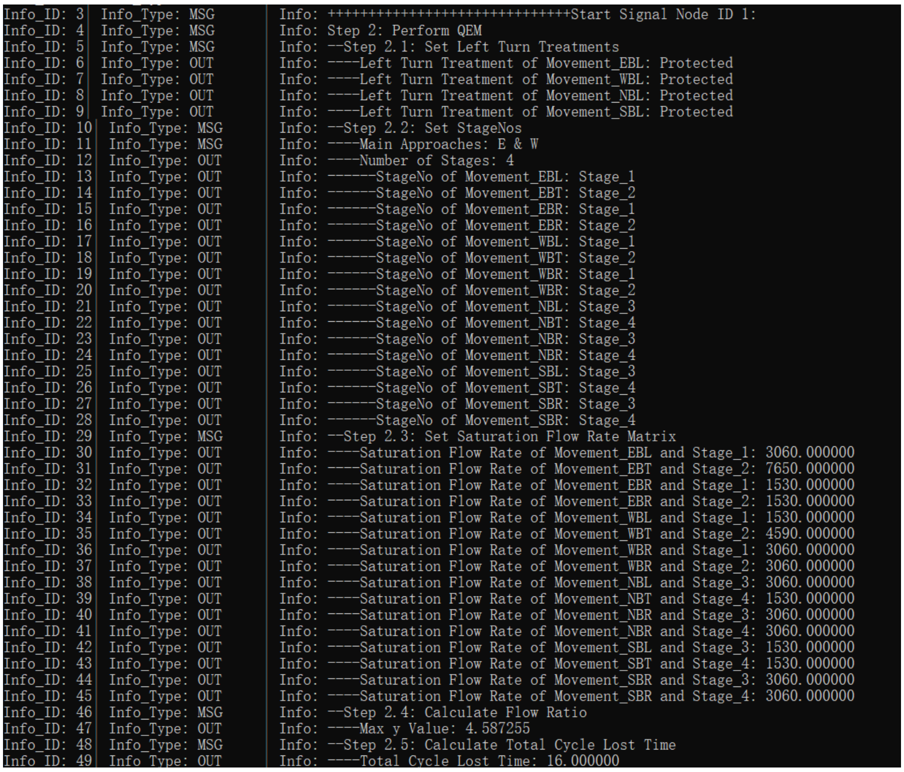


Fig.6 Location of the file “main_api.cpp”

2.5 Screen output

The output is shown partially in Fig.7. The users can check the console for the entire display, and read the user guide to understand a detailed process of the underlying QEM method, based on a particular data set.



```
Info_ID: 3  Info_Type: MSG    Info: ++++++++++++++++++++++++++++++Start Signal Node ID 1:
Info_ID: 4  Info_Type: MSG    Info: Step 2: Perform QEM
Info_ID: 5  Info_Type: MSG    Info: --Step 2.1: Set Left Turn Treatments
Info_ID: 6  Info_Type: OUT    Info: ----Left Turn Treatment of Movement_EBL: Protected
Info_ID: 7  Info_Type: OUT    Info: ----Left Turn Treatment of Movement_WBL: Protected
Info_ID: 8  Info_Type: OUT    Info: ----Left Turn Treatment of Movement_NBL: Protected
Info_ID: 9  Info_Type: OUT    Info: ----Left Turn Treatment of Movement_SBL: Protected
Info_ID: 10  Info_Type: MSG   Info: --Step 2.2: Set StageNos
Info_ID: 11  Info_Type: MSG   Info: ----Main Approaches: E & W
Info_ID: 12  Info_Type: OUT   Info: ----Number of Stages: 4
Info_ID: 13  Info_Type: OUT   Info: ------StageNo of Movement_EBL: Stage_1
Info_ID: 14  Info_Type: OUT   Info: ------StageNo of Movement_EBT: Stage_2
Info_ID: 15  Info_Type: OUT   Info: ------StageNo of Movement_EBR: Stage_1
Info_ID: 16  Info_Type: OUT   Info: ------StageNo of Movement_EBR: Stage_2
Info_ID: 17  Info_Type: OUT   Info: ------StageNo of Movement_WBL: Stage_1
Info_ID: 18  Info_Type: OUT   Info: ------StageNo of Movement_WBT: Stage_2
Info_ID: 19  Info_Type: OUT   Info: ------StageNo of Movement_WBR: Stage_1
Info_ID: 20  Info_Type: OUT   Info: ------StageNo of Movement_WBR: Stage_2
Info_ID: 21  Info_Type: OUT   Info: ------StageNo of Movement_NBL: Stage_3
Info_ID: 22  Info_Type: OUT   Info: ------StageNo of Movement_NBT: Stage_4
Info_ID: 23  Info_Type: OUT   Info: ------StageNo of Movement_NBR: Stage_3
Info_ID: 24  Info_Type: OUT   Info: ------StageNo of Movement_NBR: Stage_4
Info_ID: 25  Info_Type: OUT   Info: ------StageNo of Movement_SBL: Stage_3
Info_ID: 26  Info_Type: OUT   Info: ------StageNo of Movement_SBT: Stage_4
Info_ID: 27  Info_Type: OUT   Info: ------StageNo of Movement_SBR: Stage_3
Info_ID: 28  Info_Type: OUT   Info: ------StageNo of Movement_SBR: Stage_4
Info_ID: 29  Info_Type: MSG   Info: --Step 2.3: Set Saturation Flow Rate Matrix
Info_ID: 30  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_EBL and Stage_1: 3060.000000
Info_ID: 31  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_EBT and Stage_2: 7650.000000
Info_ID: 32  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_EBR and Stage_1: 1530.000000
Info_ID: 33  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_EBR and Stage_2: 1530.000000
Info_ID: 34  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_WBL and Stage_1: 1530.000000
Info_ID: 35  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_WBT and Stage_2: 4590.000000
Info_ID: 36  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_WBR and Stage_1: 3060.000000
Info_ID: 37  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_WBR and Stage_2: 3060.000000
Info_ID: 38  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_NBL and Stage_3: 3060.000000
Info_ID: 39  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_NBT and Stage_4: 1530.000000
Info_ID: 40  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_NBR and Stage_3: 3060.000000
Info_ID: 41  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_NBR and Stage_4: 3060.000000
Info_ID: 42  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_SBL and Stage_3: 1530.000000
Info_ID: 43  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_SBT and Stage_4: 1530.000000
Info_ID: 44  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_SBR and Stage_3: 3060.000000
Info_ID: 45  Info_Type: OUT   Info: ----Saturation Flow Rate of Movement_SBR and Stage_4: 3060.000000
Info_ID: 46  Info_Type: MSG   Info: --Step 2.4: Calculate Flow Ratio
Info_ID: 47  Info_Type: OUT   Info: ----Max y Value: 4.587255
Info_ID: 48  Info_Type: MSG   Info: --Step 2.5: Calculate Total Cycle Lost Time
Info_ID: 49  Info_Type: OUT   Info: ----Total Cycle Lost Time: 16.000000
```

Fig.7 Screen output for signal timing optimization result

3 Brief introduction on computational steps of QEM

Step 1. Input information

Movement volume and number of lanes:

Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Volume												
No. of lanes												
Shared lanes												

Step 2. Determine left-turn treatment

(1) Left-turn lane check

Criterion: If the number of left-turn lane on any approach exceeds 1, then it is recommended that the left turns on that approach be protected.

(2) Minimum volume Check

Criterion: If left-turn volume on any approach exceeds 240 veh/h, then it is recommended that the left turns on that approach be protected.

(3) Opposing Through Lanes Check

Criterion: If there are more than 4 or more through lanes on the opposing approach, then it is recommended that the left turns on that approach be protected.

(4) Opposing Traffic Speed Check

Criterion: If the opposing traffic speed exceeds 45mph, then it is recommended that the left turns on that approach be protected.

(5) Minimum Cross-Product Check

Criterion:

Protected+permissive:

Number of Through Lanes	**Minimum Cross-Product**
1	50000
2 or more	100000

Protected only:

Number of Through Lanes	**Minimum Cross-Product**
1	150000
2 or more	300000

Calculation: cross-product for each left-turn

Movement	EBL	WBL	NBL	SBL
Opposing Through Lanes				
Cross-Product				
Exceed Protected Minimum Cross-Product?(Y/N)				
Exceed Protected+Permissive Minimum Cross-Product?(Y/N)				
Protected decision				

Based on the analysis above, we can reach the left-turn final decision.

Left-turn Final Decision

Movement	EBL	WBL	NBL	SBL
Left-turn Treatment				

Step 3. Determine Ring-Barrier Structure and Movements

	Final Ring-Barrier Structure

Ring1				
Ring2				

	Final Ring-Barrier Movement			
Ring1				
Ring2				

Step 4. Adjust Lane Volumes (Calculate Analysis Flow Rate, not fully implemented in Signal API)

(1) Right-turn Movement

Right-Turn Movement		
	Exclusive RT Lane	Shared RT Lane
RT volume, V_R (veh/h)		
Number of exclusive RT lanes, N_{RT}		use 1
RT adjustment factor,[1] f_{RT}		
RT volume per lane, V_{RT} (veh/h/ln) $V_{RT} = \frac{V_R}{(N_{RT} \times f_{RT})}$		

(2) Left-turn Movement

Left-Turn Movement	
LT volume, V_L (veh/h)	
Opposing mainline volume, V_o (veh/h)	
Number of exclusive LT lanes, N_{LT}	
LT adjustment factor,[2] f_{LT}	
LT volume per lane,[3] V_{LT} (veh/h/ln) $V_{LT} = \frac{V_L}{(N_{LT} \times f_{LT})}$	Permitted LT <u>use 0</u> Protected LT ______ Not Opposed LT ______

(3) Through Movement

Through Movement			
	Permitted LT	Protected LT	Not Opposed LT
Through volume, V_T (veh/h)			
Parking adjustment factor, f_p			
Number of through lanes, N_{TH}			
Total approach volume,[4] V_{tot} (veh/h) $V_{tot} = \frac{[V_{RT}(\text{shared}) + V_T + V_{LT\,(\text{not opp})}]}{f_p}$			

(4) Through Movement with exclusive LT lane & shared LT lane

Through Movement with Exclusive LT Lane			
Through volume per lane, V_{TH} (veh/h/ln) $V_{TH} = \frac{V_{tot}}{N_{TH}}$			
Critical lane volume,[5] V_{CL} (veh/h) Max[V_{LT}, V_{RT} (exclusive), V_{TH}]			
Through Movement with Shared LT Lane			
Proportion of left turns, P_{LT}		Does not apply	Does not apply
LT equivalence, E_{L1} (Exhibit C16-3)		Does not apply	Does not apply
LT adjustment, f_{DL} (Exhibit A10-6)			use 1.0
Through volume per lane, V_{TH} (veh/h/ln) $V_{TH} = \frac{V_{tot}}{(N_{TH} \times f_{DL})}$			
Critical lane volume,[5] V_{CL} (veh/h) Max[V_{RT}(exclusive), V_{TH}]			

(5) Saturation flow rate

for protected phase:

The default value of saturation flow rate for protected phase is 1530veh/h/lane

$$Saturation\ flow\ rate(veh/h)\ =\ 1530 \times num\_of\_left\_turn\_lanes \times PHF$$

for permissive phase(for left-turn):

The default value of saturation flow rate for permissive phase is 150-200veh/h/lane

$$Saturation\ flow\ rate\ =\ f_{lu} \times f_{hv} \times opposing\_volume \times \frac{e^{-opposing\_volume \times 4.5/3600}}{1 - e^{-opposing\_volume \times 2.5/3600}}$$

Step 5. Determine Critical Lane Group

To determine the critical lane group for each stage, we should select the lane group with maximum v/s(v: volume, s: saturation rate) for each stage.

Step 6. Calculate sum of the flow ratios

The sum of the flow ratios for the critical lane groups for this phasing plan will be needed for the next section. Since this phasing plan does not include any overlapping phases, this value is simply the sum of the highest lane group *v/s* ratios for the three stages, as follows:

$$Y_c = \sum_{i=1}^{n} (\frac{v}{s})_{ci}$$

where

$Y_c\ =\ sum\ of\ flow\ ratios\ for\ critical\ lanes\ groups,$

$(v/s)_{ci} =\ flow\ ratio\ for\ critical\ lane\ group\ i, and$

$n\ =\ number\ of\ critical\ lane\ groups$

Step 7. Calculate total cycle lost time

The total lost time for the cycle will also be used in the calculation of cycle length. In determining the total lost time for the cycle, the general rule is to apply the lost time for a critical lane group when its movements are initiated (the start of its green interval).

The total cycle lost time is given as

$$L = \sum_{i=1}^{n} (t_L)_{ci}$$

where

$L = sum\ of\ lost\ time\ for\ cycle\ in\ seconds,$

$(t_L)_{ci} = total\ lost\ time\ for\ critical\ lane\ group\ i\ in\ seconds, and$

$n = number\ of\ critical\ lane\ groups$

Step 8. Calculate minimum Cycle Length and Optimal Cycle Length

(1) calculation of minimum cycle length:

$$C_{\boldsymbol{min}} = \frac{L \times X_{\boldsymbol{c}}}{X_{\boldsymbol{c}} - \sum_{i=1}^{n} \left(\frac{v}{s}\right)_{ci}}$$

where

$C_{\boldsymbol{min}} = minumum\ necessary\ cycle\ length\ in\ seconds\ (typically\ rounded\ up$
$to\ the\ nearest\ 5 - second\ increment\ in\ practice)$

$L = total\ lost\ time\ for\ cycle\ in\ seconds,$

$X_{\boldsymbol{c}} = critical\ v/c\ ratio\ for\ the\ intersection,$

$(v/s)_{ci} = flow\ ratio\ for\ critical\ lane\ group\ i, and$

$n = number\ of\ critical\ lane\ groups$

(2) calculation of optimal cycle length:

A practical equation for the calculation of the cycle length that seeks to minimize vehicle delay was developed by Webster (1969). Webster's optimum cycle length formula is

$$C_{opt} = \frac{1.5 \times L + 5}{1.0 - \sum_{i=1}^{n} \left(\frac{v}{s}\right)_{ci}}$$

where

$C_{\boldsymbol{min}} = cycle\ length\ to\ minimize\ delay\ in\ seconds,$
$and\ other\ terms\ are\ as\ defined\ previously$

The analytical cycle length determined from the above calculation is only approximate in nature, and should be further adjusted to the real-world considerations. Webster noted that values between $0.75C_{opt}$ and $1.5C_{opt}$ will likely give similar values of delay, and engineers typically select a cycle length as a multiplier of 5 or 10 seconds, e.g., 70 seconds, as oppose to 67.5 seconds.

Step 9. Allocate green time and calculate effective green time

There are several strategies for allocating the green time to the various stages. One of the most popular and simplest is to distribute the green time so that the *v/c* ratios are equalized for the critical lane groups, as by the following equation:

$$g_i = \left(\frac{v}{s}\right)_{ci}\left(\frac{C}{X_i}\right)$$

where

$g_i = effective\ green\ time\ for\ phase\ i,$

$(v/s)_{ci} = flow\ ratio\ for\ critical\ lane\ group\ i,$

$C = cycle\ length\ in\ seconds, and$

$X_i = v/c\ ratio\ for\ lane\ group\ i,$

Effective green time is calculated as follows:

$$g = G + Y + AR - t_L$$

where

$g = effective\ green\ time\ for\ a\ traffic\ movement\ in\ seconds,$

$G = displayed\ green\ time\ for\ a\ traffic\ movement\ in\ seconds,$

$Y = displayed\ yellow\ time\ for\ a\ traffic\ movement\ in\ seconds,$

$AR = displayed\ all - red\ time\ in\ seconds, and$

$t_L = total\ lost\ time\ for\ a\ movement\ during\ a\ cycle\ in\ seconds.$

Step10. Calculate capacity and V/C ratio

Capacity can be calculated as follows:

$$c = s \times g/C$$

where

$c = capacity\ (the\ maximum\ hourly\ volume\ that\ can\ pass\ through\ an\ intersection\ from\ a\ lane\ or\ group\ of\ lanes\ under\ prevailing\ roadway, traffic, and\ control\ conditions)\ in\ veh/h$

$s = saturation\ flow\ rate\ in\ veh/h, and$

$g/C = ratio\ of\ effective\ green\ time\ to\ cycle\ length$

Then we can calculate the ratio of V/C.

Step11. Calculate Signal Delay and LOS

(1) Average Uniform Delay

$$d_1 = \frac{0.5C(1-\frac{g}{C})^2}{1-(\frac{v}{c}\times\frac{g}{C})}$$

(2) Average Incremental Delay (not fully implemented in Signal API)

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8KIX}{cT}}\right]$$

where

$d_2 =$ *average incremental delay per vehicle due to random arrivals and occasional oversaturation in seconds,*

$T =$ *duration of analysis period in h,*

$X =$ *v/c ratio for lane group,*

$k =$ *delay adjustment factor that is dependent on signal controller mode,*

$I =$ *upstream filtering/metering adjustment factor, and*

$c =$ *lane group capacity in veh/h.*

(3) Control Delay

$$Control\ Delay = Average\ Uniform\ Delay + Average\ Incremental\ Delay$$

(4) Approach Delay

$$d_A = \frac{\sum_i d_i v_i}{\sum_i v_i}$$

where

$d_A =$ *average delay per vehicle for approach A in seconds,*

$d_i =$ *average delay per vehicle for lane group i (on approach A) in seconds, and*

$v_i =$ *analysis flow rate for lane group i in veh/h*

(5) Intersection Delay

$$d_I = \frac{\sum_A d_A v_A}{\sum_A v_A}$$

where

$d_I =$ *average delay per vehicle for the intersection in seconds,*

$d_A =$ *average delay per vehicle for approach A in seconds, and*

$v_A =$ *analysis flow rate for approach A in veh/h*

(6) LOS for each lane group, each approach and the intersection

The corresponding relationship between LOS and control delay is shown in Table 3:

Table 3. The relationship of LOS and Control delay

LOS	Control delay per vehicle
A	⩽10
B	>10-20
C	>20-35
D	>35-55
E	>55-80
F	>80

References

Traffic Control Systems Handbook https://ops.fhwa.dot.gov/publications/fhwahop06006/

Traffic Signal Timing Manual https://ops.fhwa.dot.gov/publications/fhwahop08024/

Signalized Intersections: Informational Guide https://www.fhwa.dot.gov/publications/research/safety/04091