FINAL REPORT

to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
SYSTEMS PLANNING OFFICE

on Project

"Improvements and Enhancements to LOSPLAN 2009"

FDOT Contract BDK-77-977-05, (UF Project 00081431)

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University of Florida
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Disclaimer

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

This project addressed several aspects of the LOSPLAN software, primarily with respect to incorporating new FDOT and NCHRP research project results. In addition, some existing computational methodology aspects were refined to provide more accurate results and clearer guidance to users.

The updated software can be found at the following URL:
http://www.dot.state.fl.us/planning/systems/sm/los/los_sw2m2.shtm#software

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- Robin Osborne (for the task on estimating g/C for unsignalized intersection analysis)
- Seckin Ozkul (for the task on updating the multimodal analysis methodologies)
- Kevin Marquez (for the task on the relationship between g/C and cycle length)

Notes

Some of the material presented in this report was originally developed in the Mathcad[1] software program. You will notice several notation conventions that you may not be familiar with if you are not a Mathcad user. Most of these notation conventions are self-explanatory or easily understood. The most common Mathcad specific notations in this material relates to the equals sign. You will notice two different notations for the equals sign being used in the Mathcad material presented in this report. The differences between these equals sign notations are explained as follows.

- The ':=' (colon-equals) is an assignment operator, that is, the value of the variable or expression on the left side of ':='is set equal to the value of the expression on the right side. For example, in the statement, L := 1234, the variable 'L' is assigned (i.e., set equal to) the value of 1234. Another example is x := y + z. In this case, x is assigned the value of y + z.

- The '=' (standard equals) is used for a simple numeric evaluation. For example, referring to the x := y + z assignment used previously, if the value of y was 10 and the value of z was 15, then the expression 'x =' would yield 25. Another example would be as follows: s := 1800/3600, with s = 0.5. That is, 's' was assigned the value of 1800 divided by 3600 (using :=), which equals 0.5 (as given by using =).

[1] http://www.ptc.com/products/mathcad/

Improvements and Enhancements to LOSPLAN 2009

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Introduction

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http://www.dot.state.fl.us/planning/systems/sm/los/los_sw2m2.shtm#software

Overview of Changes to LOSPLAN Software

The section outlines the general changes made to each of the LOSPLAN programs.

ARTPLAN

1. Revise current method described in Q/LOS Handbook (p. 76) [*1*] for accommodating two-way and all-way stop control conditions. It is expected that the revised method will remain a relatively simple method, yet will be more accurate and intuitive than the current method.

   The revised equations are as follows:

   Two-way stop control:

   Without Left-Turn Bays

   $$Est.\ g/C = 0.556666 + 0.\ 000968 \times MainStreetVol - 0.000006 \times MainStreetVol^2 + 0.000446 \times CrossStreetVol - 0.000003 \times CrossStreetVol^2 - 0.413692 \times (PctLeftTurns/100) + 0.707765 \times (PctLeftTurns/100)^2$$

   With Left-Turn Bays

   $$Est.\ g/C = 0.501495 + 0.000989 \times MainStreetVol - 0.000005 \times MainStreetVol^2 + 0.000578 \times CrossStreetVol - 0.000003 \times CrossStreetVol^2 - 0.136783 \times (PctLeftTurns/100) + 0.756259 \times (PctLeftTurns/100)^2$$

   All-way stop control:

   Without Left-Turn Bays

   $$Est.\ g/C = 0.05336429 + 0.00403063 \times MainStreetVol - 0.00001033 \times MainStreetVol^2 + 0.00136678 \times CrossStreetVol - 0.00000291 \times CrossStreetVol^2 + 0.37614667 \times (PctLeftTurns/100) - 1.25347703 \times (PctLeftTurns/100)^2$$

   With Left-Turn Bays

$Est.\ g/C = 0.637963 + 0.000971 \times MainStreetVol - 0.000004 \times MainStreetVol^2 - 0.000440 \times CrossStreetVol + 0.0000000424 \times CrossStreetVol^2 + 0.140119 \times (PctLeftTurns/100) + 1.196012 \times (PctLeftTurns/100)^2$

Where:

Est. g/C = estimated effective green time to cycle length ratio
MainStreetVol = directional hourly volume on the main street, in veh/h
CrossStreetVol = directional hourly volume, for the heaviest of the two directions, on the cross street, in veh/h
PctLeftTurns = percentage of directional hourly volume on main street turning left

A complete description of the results of this task is given in Appendix A.

Currently, to avoid the addition of a new input field in ARTPLAN, a two-way stop controlled intersection is indicated by entering a cycle length of 0 and an all-way stop stop-controlled intersection is indicated by entering a cycle length of 1. After a cycle length entry of 0 or 1, the "Thru g/C" entry cell will be disabled, as the value calculated from the appropriate equation above will be entered into this cell. A cycle length of 120 seconds is used internally for the signal delay calculations, as this was the assumed value for the estimated *g*/*C* ratio equation development.

2. Implement revised truck passenger car equivalent (PCE) and start-up lost time values based on FDOT project BD-545-51 [*2*].

   The PCE value was revised (to 2.3). Lost time was not revised since it is not accounted for in ARTPLAN—the effective green time is determined explicitly from entered g/C value

3. Implement methodology for determination of through movement flow rate as a function of left-turn spillover, based on FDOT project BD-545-84 [*3*].

   The following equations were implemented.

   Single Through-Lane Model:

$$Thruput = 799.0094 - 6.8054 \times \%LT - 43.8500 \times L - 30.9825 \times G_{LT} + 1.3245 \times G_{TH} + 0.9251 \times C + 0.4918 \times D + 0.6805 \times \%LT \times L + 0.9152 \times \%LT \times G_{LT} - 0.2896 \times \%LT \times G_{TH} + 0.0338 \times \%LT \times C - 0.0161 \times \%LT \times D + 0.6493 \times L \times G_{LT} + 0.1148 \times L \times G_{TH} + 0.0241 \times L \times D + 0.0571 \times G_{LT} \times G_{TH} + 0.0109 \times G_{LT} \times D + 0.0056 \times G_{TH} \times D - 0.0045 \times C \times D$$

   Where:
   Thruput = through lane vehicle discharge rate (veh/h)
   %LT = percent of the approach demand turning left

L = left-turn storage length (veh)[1]
G_{LT} = green time for left-turn movement (s)
G_{TH} = green time for through movement (s)
C = cycle length (s)
D = approach demand (veh/h/lane)

Multiple Through-Lane Model:

$$Thruput = 932.6415 - 21.6749 \times \%LT - 41.9322 \times L - 100.4621 \times G_{LT} - 39.4056 \times G_{TH} + 8.8626 \times C + 0.5795 \times D + 731.7854 \times NumLanes + 0.9569 \times \%LT \times L + 1.5033 \times \%LT \times G_{LT} - 0.5604 \times \%LT \times G_{TH} + 0.0732 \times \%LT \times C - 0.0314 \times \%LT \times D - 5.0604 \times \%LT \times NumLanes + 0.2749 \times L \times C + 0.5900 \times G_{LT} \times G_{TH} + 0.0281 \times G_{LT} \times D + 5.5910 \times G_{LT} \times NumLanes + 0.0586 \times G_{TH} \times C + 0.0293 \times G_{TH} \times D + 6.8871 \times G_{TH} \times NumLanes - 0.0151 \times C \times D - 3.9624 \times C \times NumLanes + 0.1671 \times D \times NumLanes$$

Where:
Thruput = through lanes vehicle discharge rate (veh/h)
%LT = percent of the average per lane approach demand turning left
L = left-turn storage length (veh)
G_{LT} = green time for left-turn movement (s)
G_{TH} = green time for through movement (s)
C = cycle length(s)
D = average approach demand (veh/h/lane)
NumLanes = number of through lanes

The basic process in applying these equations is as follows:

- The through movement volume is calculated assuming no impact from left turn spillover.
- The impact of left turn spillover, if any, is determined from the above equations. The corresponding through movement volume is assigned to an adjusted through movement volume variable.
- The difference between the unadjusted and adjusted through movement volume is assigned to a residual demand variable. The residual demand is assumed to be zero for the first intersection in the analysis network.
- The queue storage ratio is calculated for the segment based on the residual demand. If the queue storage ratio exceeds 1.0, a warning message is given in the results screen.
- The demand on the downstream segment is adjusted by subtracting out the residual demand of the upstream segment (the through volume that was not able to discharge due to the left turn spillover).
- This process is repeated for each subsequent downstream intersection and segment.

[1] This includes vehicle length plus spacing between vehicles. Twenty five feet per vehicle was used in this study.

4. Revise signal controller type input and corresponding effect on calculations to reflect actuated-coordinated signal timing plans.

   The following revisions were made to ARTPLAN:

   The ‘Control Type’ input labels were changed as follows:

Former Labels	New Labels
Pretimed	PretimedCoord
Semiactuated	ActuatedCoord
Actuated	FullyActuated

   The signal control type and arrival type defaults were made a function of both area type and arterial class, and set as follows:

Area Type	Class	Signal Control	Arrival Type
Large Urbanized	1-3	ActuatedCoord	4
	4	PretimedCoord	5
Other Urbanized	1-3	ActuatedCoord	4
	4	PretimedCoord	5
Transitioning	1-4	ActuatedCoord	4
Rural Developed	1	FullyActuated	3
	2-4	ActuatedCoord	4

5. Develop guidance for the input of *g*/*C* ratio as a function of cycle length.

   The results of this task are described in Appendix B.

6. Update the multimodal calculations based on the results from NCHRP 3-70 [*4, 5*].
   a. Revise the bicycle, pedestrian, and bus calculations as necessary
   b. Add the calculation methodologies for bicycle and pedestrian signalized intersection LOS (currently, the ARTPLAN bicycle and pedestrian LOS is calculated only for segments)

   The revisions to the software code are reflected in the updated ARTPLAN computations documentation, which is shown in Appendix C.

   To accommodate these calculations revisions, two new inputs were added to the “Segment (Auto)” screen: one for the presence of on-street parking and one for the level of parking activity. While these inputs will affect the multimodal calculations, the presence of on-street parking can obviously also affect the performance of the auto mode. However, the NCHRP 3-70 auto methodology does not include a method for estimating the delay due to on-street parking maneuvers. Until a more rigorous procedure can be developed, a very simple delay adjustment has been included for now, as follows.

```
OnStreetParking := 1          0 = No, 1 = Yes

ParkingActivity := 2          0 = Not Applicalbe, 1 = Low, 2 = Medium, 3 = High

OtherDelay := | return 0  if  OnStreetParking = 0
              | if  OnStreetParking = 1
              |    | return 1.0  if  ParkingActivity = 1
              |    | return 3.0  if  ParkingActivity = 2        planning level assumptions
              |    | return 5.0  if  ParkingActivity = 3

OtherDelay = 3.0          sec/veh
```

Figure 1. Calculations for effect of on-street parking on delay

The “OtherDelay” value is factored into the new running time calculation, as described under Task 9.

Three new inputs were added to the “Segment (MM)” screen: one for the bus passenger load factor, one for the level of bus stop amenities, and one for whether the bus makes an intersection near-side stop. Two previous inputs were removed from this screen: the obstacle to bus stop input and the bus span of service input.

Other inputs needed for the revised calculations were derived from existing ARTPLAN inputs.

A screen capture showing the “Segment (Auto)” screen with the new inputs is shown in Figure 2.

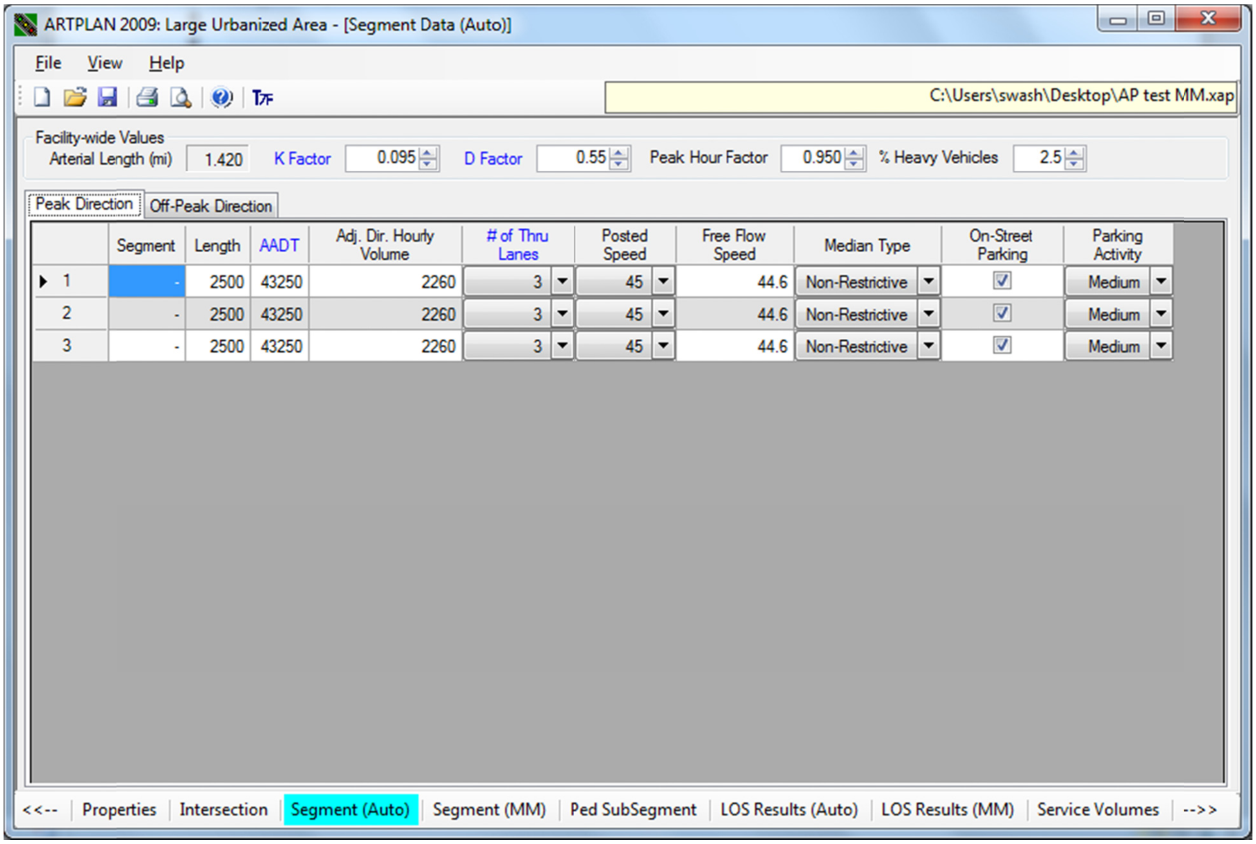


Figure 2. "Segment (Auto)" screen with new inputs

A screen capture showing the “Segment (MM)” screen with the new inputs is shown in Figure 3Figure 2.

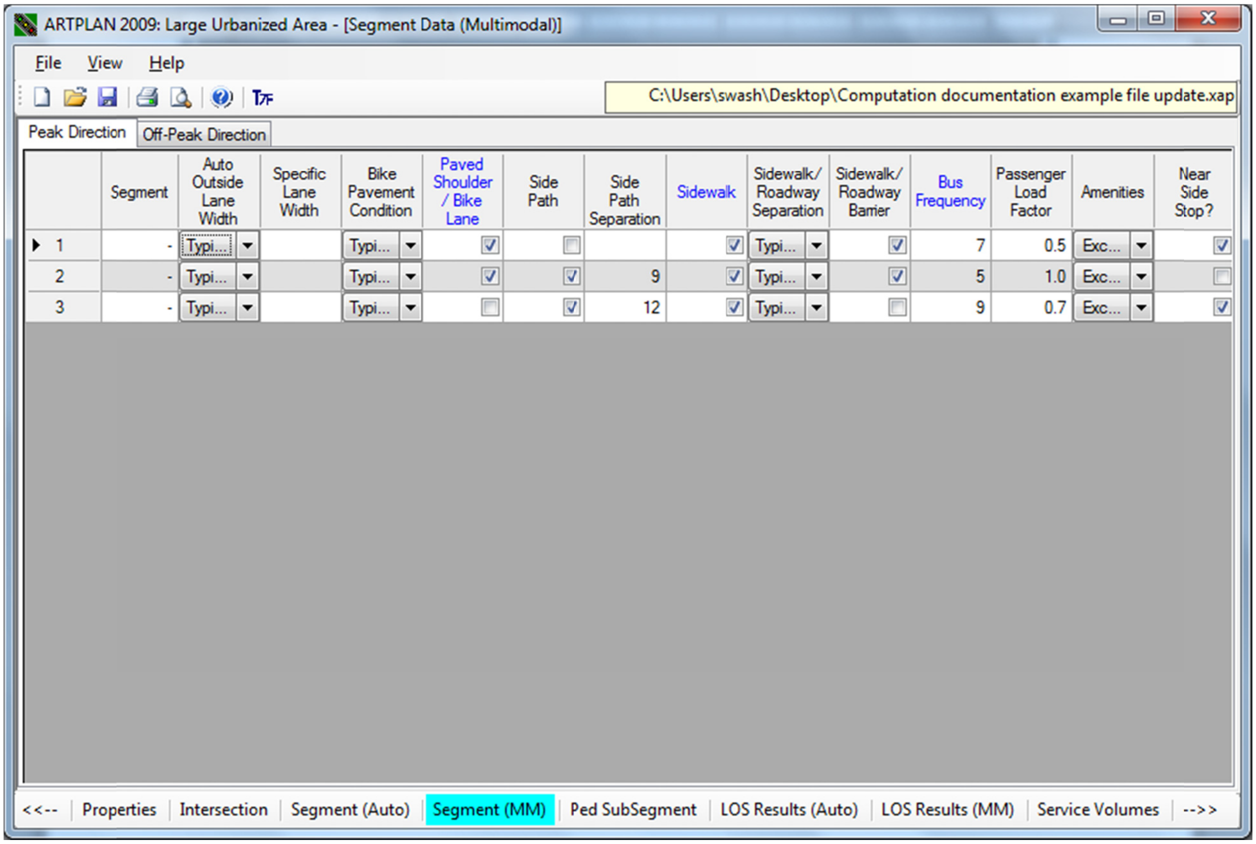


Figure 3. "Segment (MM)" screen with new inputs

Screen captures showing the revised “LOS Results (MM)” screen, which reflect the new multimodal analysis outputs, are shown in Figure 4 and Figure 5.

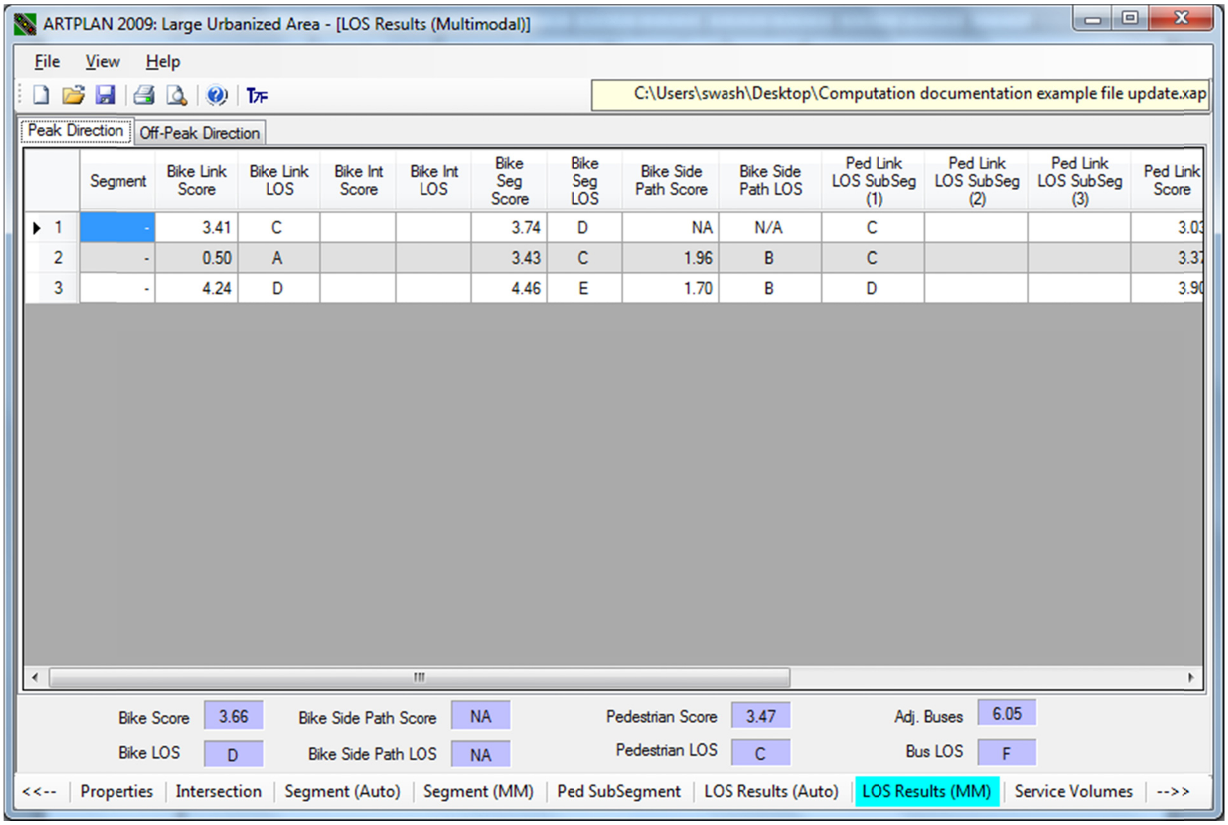


Figure 4. "LOS Results (Multimodal)" screen with new outputs, part 1

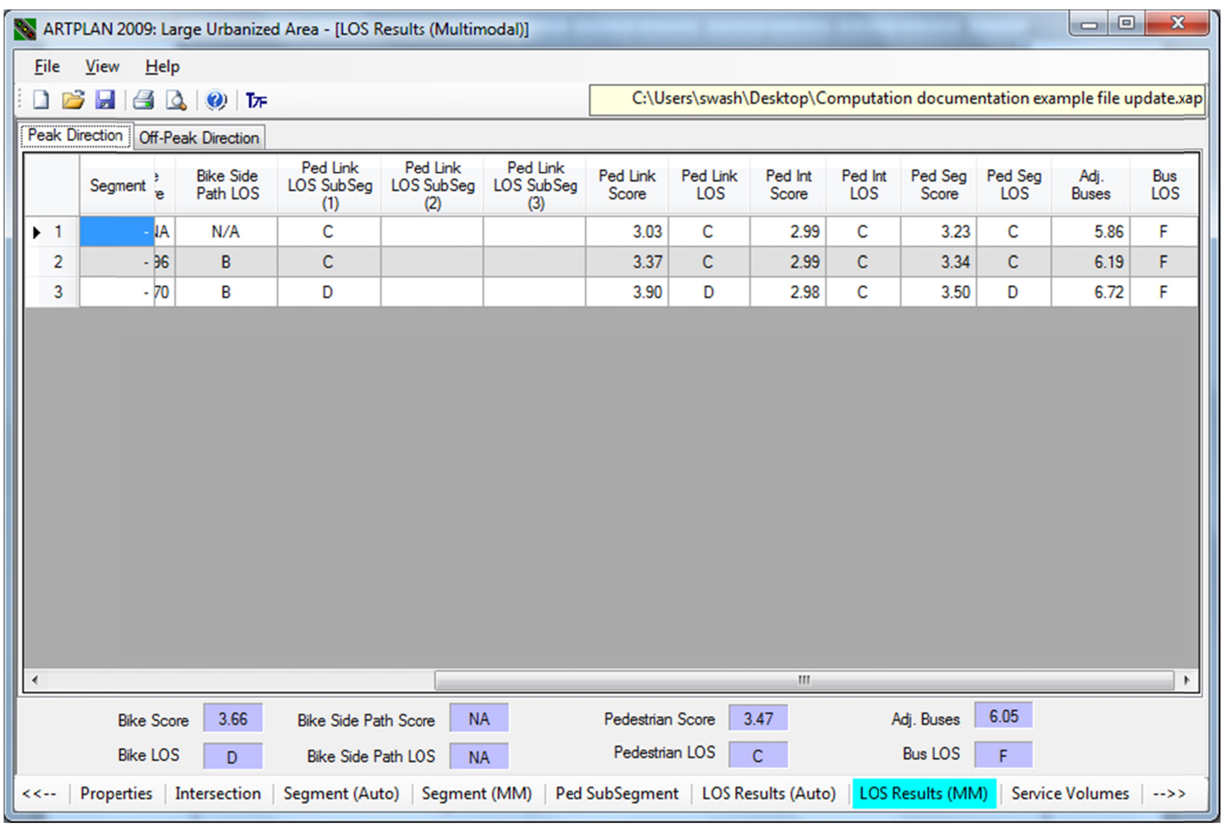


Figure 5. "LOS Results (Multimodal)" screen with new outputs, part 2

7. Implement the impact of trucks (on bike LOS) based on FDOT project BD-545-81 [*6*].

   The following revisions to the ARTPLAN computations documentation reflect the changes made to the software code.

B. Calculate the truck factor [per FDOT project # BD-545-81 (PI: Linda Crider)]

$$TF(i) := \begin{array}{|l} out \leftarrow \left[\dfrac{\dfrac{v_{15}(i)}{SegNumLanes_{(i)}} \cdot \dfrac{\%HV}{100}}{3}\right] \cdot \dfrac{\%HV}{100} \quad \text{if } \left[\dfrac{v_{15}(i)}{SegNumLanes_{(i)}}\right] \cdot \dfrac{\%HV}{100} \le 3 \\ out \leftarrow \dfrac{\%HV}{100} \quad \text{otherwise} \end{array}$$

TF(1) = 0.025
TF(2) = 0.025
TF(3) = 0.025

2a. Determine On-Street Segment Bicycle LOS.

$$BikeScore(i) := 0.507 \cdot \ln\left(\frac{v_{15}(i)}{NumDirLanes_i}\right) + 0.199 \cdot SP_t(i) \cdot (1 + 10.38 \cdot TF(i))^2 + 7.066 \cdot \left(\frac{1}{PR(i)}\right)^2 - 0.005 \cdot We(i)^2 + 0.76$$

Figure 6. Calculations for adjustment to bicycle LOS due to trucks

8. Implement bicycle side path LOS calculation developed by Sprinkle Consulting [*7*].

   Figure 7 and Figure 8 show the new bicycle side path calculations as contained in the ARTPLAN computations documentation, which reflect the changes made to the software code.

2b. Determine SidePath Segment Bicycle LOS.

$$\text{BikeSidePathScore}(i) := \begin{vmatrix} out \leftarrow 2.75 + 0.0471 \cdot \text{RunSpeed}_i - 0.919 \cdot \ln(\text{SidePathSep}_i) & \text{if } \text{SidePath}_i = 1 \\ out \leftarrow \text{"NA"} & \text{otherwise} \end{vmatrix}$$

BikeSidePathScore(1) = "NA"

BikeSidePathScore(2) = 2.688

BikeSidePathScore(3) = 2.521

$$\text{BikeSidePathLOS}(i) := \begin{vmatrix} \text{return "NA"} \quad \text{if BikeSidePathScore}(i) = \text{"NA"} \\ \text{if BikeSidePathScore}(i) \neq \text{"NA"} \\ \quad \begin{vmatrix} \text{return "A"} & \text{if BikeSidePathScore}(i) \le 1.5 \\ \text{return "B"} & \text{if BikeSidePathScore}(i) \le 2.5 \\ \text{return "C"} & \text{if BikeSidePathScore}(i) \le 3.5 \\ \text{return "D"} & \text{if BikeSidePathScore}(i) \le 4.5 \\ \text{return "E"} & \text{if BikeSidePathScore}(i) \le 5.5 \\ \text{return "F"} & \text{if BikeSidePathScore}(i) > 5.5 \end{vmatrix} \end{vmatrix}$$

BikeSidePathLOS(1) = "NA"

BikeSidePathLOS(2) = "C"

BikeSidePathLOS(3) = "C"

Figure 7. Calculations for bicycle side path segment LOS

3b. Determine SidePath Facility Bicycle LOS.

$$\text{FacilityExists} := \begin{vmatrix} out \leftarrow 1 & \text{if } \text{SidePath}_1 = 1 \wedge \text{SidePath}_2 = 1 \wedge \text{SidePath}_3 = 1 \\ out \leftarrow 0 & \text{otherwise} \end{vmatrix}$$

$$\text{FacilityBikeScore} := \begin{vmatrix} out \leftarrow \dfrac{(\text{BikeScore}(1))^2 \text{Length}_1 + (\text{BikeScore}(2))^2 \text{Length}_2 + (\text{BikeScore}(3))^2 \text{Length}_3}{(\text{BikeScore}(1))\text{Length}_1 + (\text{BikeScore}(2))\text{Length}_2 + (\text{BikeScore}(3))\text{Length}_3} & \text{if FacilityExists} = 1 \\ out \leftarrow \text{"NA"} & \text{otherwise} \end{vmatrix}$$

FacilityBikeScore = "NA"

$$\text{FacilityBikeLOS} := \begin{vmatrix} \text{return "NA"} \quad \text{if FacilityBikeScore} = \text{"NA"} \\ \text{if FacilityBikeScore} \neq \text{"NA"} \\ \quad \begin{vmatrix} \text{return "A"} & \text{if FacilityBikeScore} \le 1.5 \\ \text{return "B"} & \text{if FacilityBikeScore} \le 2.5 \\ \text{return "C"} & \text{if FacilityBikeScore} \le 3.5 \\ \text{return "D"} & \text{if FacilityBikeScore} \le 4.5 \\ \text{return "E"} & \text{if FacilityBikeScore} \le 5.5 \\ \text{return "F"} & \text{if FacilityBikeScore} > 5.5 \end{vmatrix} \end{vmatrix}$$

FacilityBikeLOS = "NA"

Figure 8. Calculations for bicycle side path facility LOS

To accommodate these calculations revisions, two new inputs were added to the “Segment (MM)” screen: one for the presence of a side path and one for the side path separation. These inputs can be seen in the screen capture shown in Figure 3. Screen captures showing the updated multimodal LOS results screen, with the new side path outputs, can also be seen under the Task 6 description.

9. Implement new calculation procedures from NCHRP 3-79 [*8*] for the determination of segment running speed.

   The revisions to the software code are reflected in the updated ARTPLAN computations documentation (specific to the weaving methodology), which is shown in Appendix D.

10. Right-turn adjustment factor for exclusive right turn lanes

    Figure 9 shows the revisions to the ARTPLAN computations documentation, which reflect the changes made to the software code.

Adjusted Right Turn Factor (Revised)

Part of Adjusted Saturation Flow Rate Calculations

$PctRT := 10$

$RTBay := 1$

$NumIntThruLanes := 3$

$$PctMultiplier := \left| \begin{array}{l} \text{if } NumIntThruLanes > 1 \\ \quad \left| \begin{array}{l} \text{return } 0 \text{ if } PctRT < 2.5 \\ \text{return } 0.14 \text{ if } PctRT > 30 \\ \left(\text{return } 0.00007 \cdot PctRT^2 + 0.0004 \cdot PctRT + 0.0611\right) \text{ otherwise} \end{array} \right. \\ \text{if } NumIntThruLanes = 1 \\ \quad \left| \begin{array}{l} \text{return } 0 \text{ if } PctRT < 2.5 \\ \text{return } 0.13 \text{ if } PctRT > 30 \\ \left(\text{return } 0.0001 \cdot PctRT^2 + 0.0004 \cdot PctRT + 0.0253\right) \text{ otherwise} \end{array} \right. \end{array} \right.$$

$PctMultiplier = 0.072$

$$RTadjFact := \left| \begin{array}{l} out \leftarrow 1 - \left(PctMultiplier \cdot \frac{PctRT}{12}\right) \text{ if } RTBay = 1 \\ out \leftarrow \dfrac{1}{1 + \left(\frac{PctRT}{100} \cdot 0.07\right)} \text{ otherwise} \end{array} \right.$$

$RTadjFact = 0.94$

Figure 9. Calculations for right turn adjustment factor

HIGHPLAN

1. Revision to calculations for service measures to accommodate FDOT constraint for improvement to LOS due to incorporation of passing lanes.

   Figure 10 shows the revisions to the HIGHPLAN computations documentation, which reflect the changes made to the software code.

   Passing Lane Improvement

   If there is a passing lane in the analysis direction, the service volumes will be increased by the proportion of the length of the passing lane (assumed to be 1 mile) to the passing lane spacing, as illustrated below.

   $NoPassingSV := 830$ veh/h

   $Spacing := 2$ miles

   $Improvement := \frac{1}{Spacing} = 0.5$

   $PassingSV := NoPassingSV \cdot (1 + Improvement)$

   $PassingSV := PassingSV - mod(PassingSV, 10)$ * HIGHPLAN rounds down to multiples of 10

   $PassingSV = 1240$ veh/h

   Note that the improvement to the service volumes cannot exceed capacity. In other words, the service volume for any level of service is capped at the LOS E service volume for the no-passing lane condition.

   Figure 10. Calculations for passing lane adjustment

2. Implement two-lane highway facility analysis methodology based on FDOT project BC-345-89 [*9*].

   Screen captures showing the new input and output screens added to accommodate the two-lane highway facility methodology are shown in Figure 11 and Figure 12.

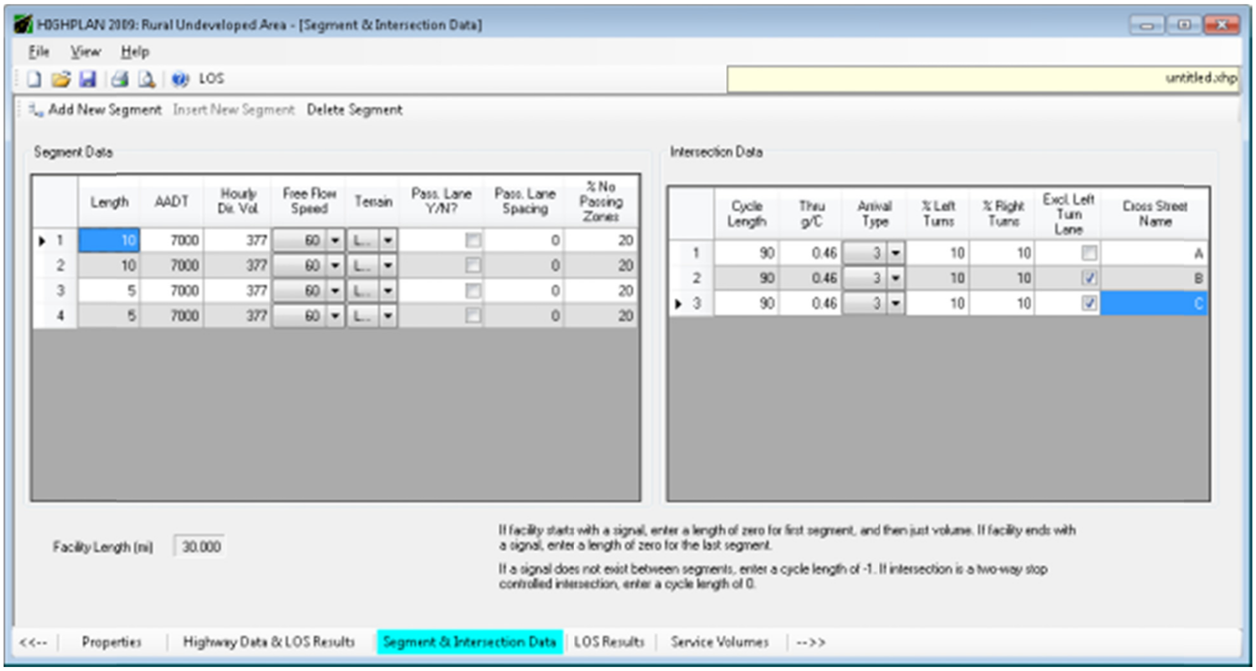


Figure 11. Two-lane highway facility inputs screen

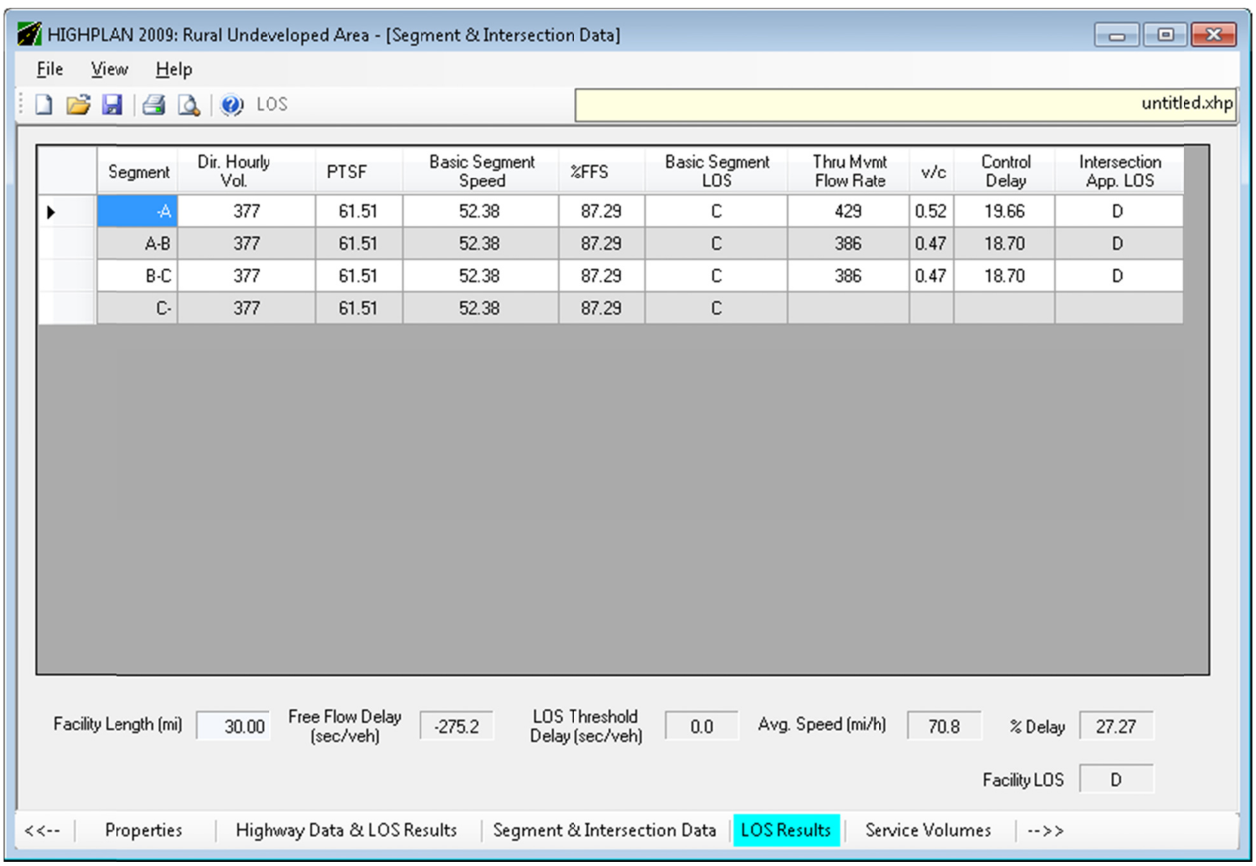


Figure 12. Two-lane highway facility analysis outputs screen

The revisions to the software code are reflected in the updated HIGHPLAN computations documentation, which is shown in Appendix E.

FREEPLAN

1. Calculate and report the *v/c* ratio performance measure results.

   The calculated *v/c* results have been added to the 'Hot Spots' screen (accessed from the 'LOS Results' screen), as shown in Figure 13.

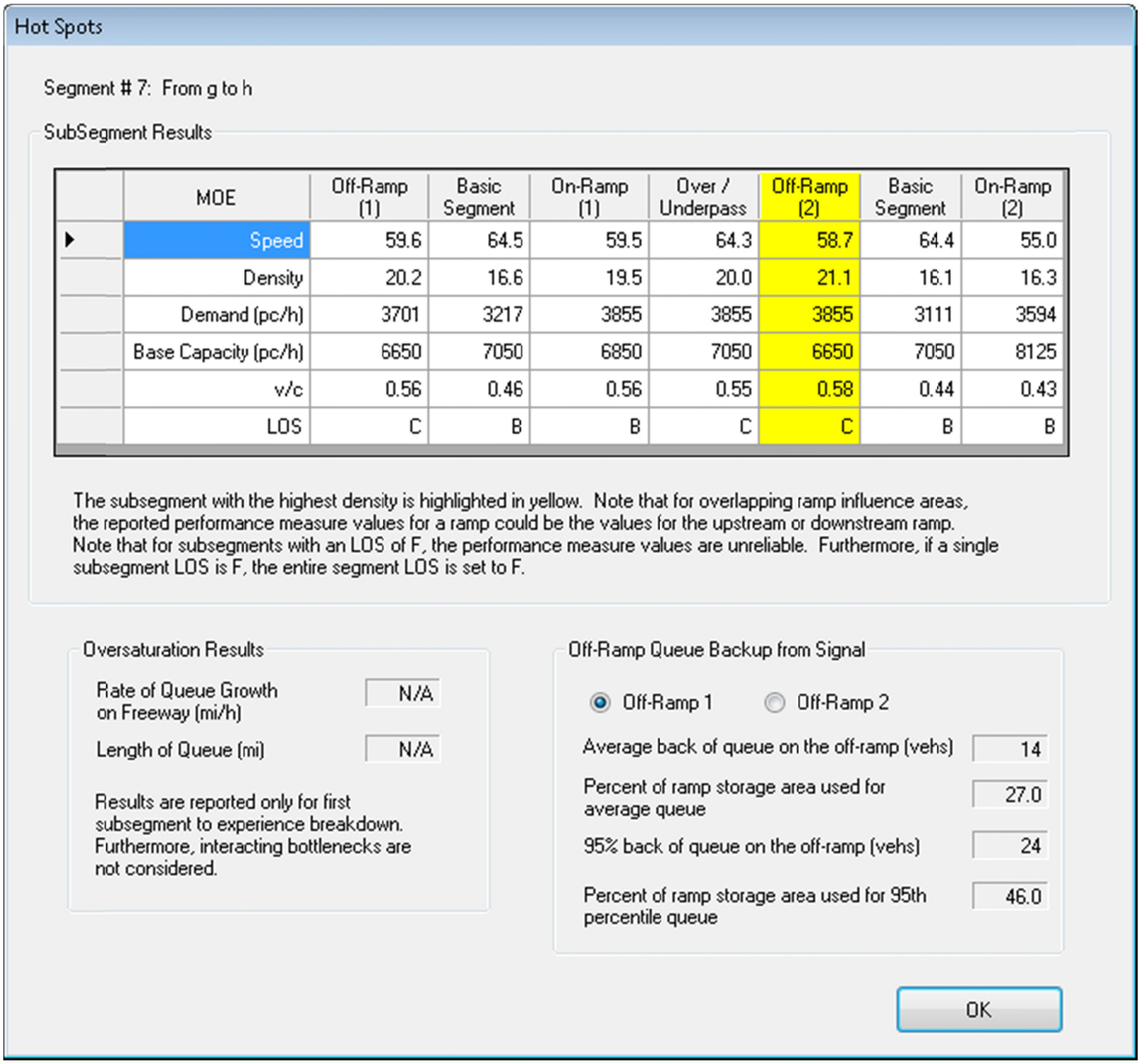


Figure 13. FREEPLAN Hot Spots screen

2. Implement new weaving analysis methodology based on NCHRP 3-75 [*10*].

   The revisions to the software code are reflected in the updated FREEPLAN computations documentation (specific to the weaving methodology), which is shown in Appendix F.

3. Reevaluate the auxiliary lane calculations.

   The recommended method for handling the effect of auxiliary lanes on freeway segment volume throughput is the method given in the final report for project FDOT project BDK-75-977-08 [*11*]. An excerpt summarizing the main recommendation from that report is given in Figure 14.

Adjustment Equation

As seen from Tables 7, 8 and 9, the percentage increase in volume throughput of the segment by adding an auxiliary lane is essentially a fixed value for a particular number of through lanes. In addition, the proportional increase does not depend on weaving volume or interchange spacing. The average percentage increase in throughput volume based on number of lanes is shown in Table 10.

Table 10. Average Percentage Increase in Volume by Adding an Auxiliary Lane

Number of Through Lanes *N*	Percentage Increase in Volume
2	48.87
3	32.03
4	23.81
5	18.71

Using the values obtained from CORSIM, two models were developed for the percentage increase in volume throughput due to auxiliary lane for a given number of mainline lanes. The general specification of the two models is given by:

Model 1: $\boldsymbol{percentage\ increase = 16.0 + 10 \times (5 - N)}$

Model 2: $\boldsymbol{percentage\ increase = 65.4 - (10.0 \times N)}$

where

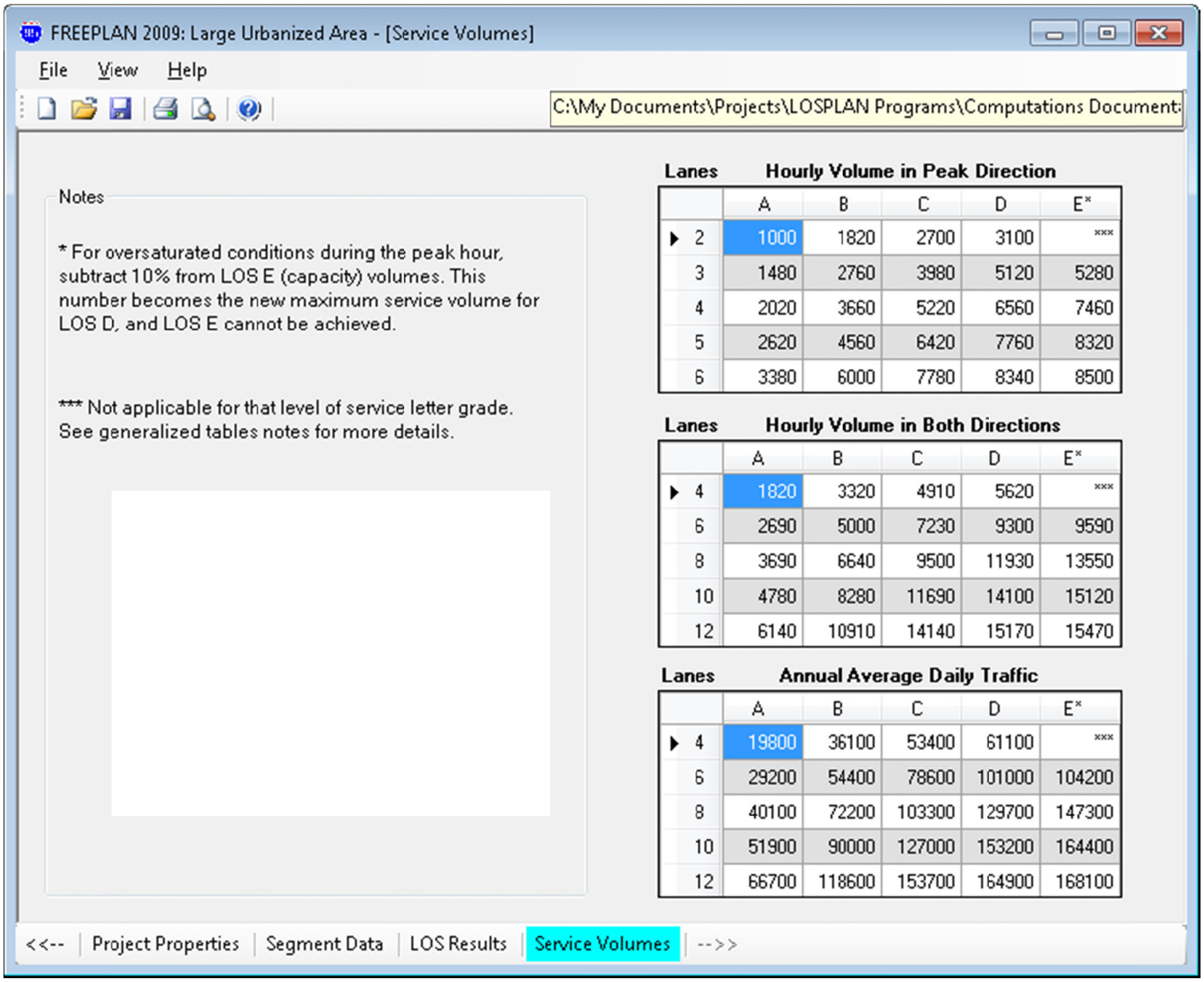
N = Number of through lanes

The two models give very similar results. The key difference is that the first model implies that it is valid only for freeway segments with a maximum of five lanes. While this was the maximum number of lanes used in the test scenarios in this study, it is possible that this relationship will hold reasonably for freeway segments with more than five lanes. Thus, if one is comfortable with that notion, the second equation could be specified.

Figure 14. Excerpt from FDOT project BDK-75-977-08 for recommendation on service volume calculation adjustment for auxiliary lanes

4. Implement FDOT's current planning assumption about impact to service volumes due to oversaturated traffic flow conditions.

   Figure 15 shows the note corresponding to the guidance given for the analysis of oversaturated conditions.



Lanes	A	B	C	D	E*
2	1000	1820	2700	3100	***
3	1480	2760	3980	5120	5280
4	2020	3660	5220	6560	7460
5	2620	4560	6420	7760	8320
6	3380	6000	7780	8340	8500

Lanes	A	B	C	D	E*
4	1820	3320	4910	5620	***
6	2690	5000	7230	9300	9590
8	3690	6640	9500	11930	13550
10	4780	8280	11690	14100	15120
12	6140	10910	14140	15170	15470

Lanes	A	B	C	D	E*
4	19800	36100	53400	61100	***
6	29200	54400	78600	101000	104200
8	40100	72200	103300	129700	147300
10	51900	90000	127000	153200	164400
12	66700	118600	153700	164900	168100

Figure 15. FREEPLAN service volumes screen showing guidance for oversaturated analysis

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8. J.A. Bonneson, M. Pratt, and M. Vandehey. *Predicting the Performance of Automobile Traffic on Urban Streets.* Final Report. NCHRP Project No. 3-79. Transportation Research Board, National Research Council, Washington, D.C., January 2008.

9. Washburn, Scott S. *Improvement of Planning Level Analysis Procedures for Two-Lane Highways*. Final Report. Florida Department of Transportation. Tallahassee, FL. October 2005. 375 pages.

10. Roess, Roger P. *Analysis of Freeway Weaving Section.* Final Report. NCHRP Project No. 3-75. Transportation Research Board, National Research Council, Washington, D.C., January 2008.

11. Washburn, Scott S, Yin, Yafeng, Modi, Vipul, and Kulshrestha, Ashish. *Investigation of Freeway Capacity*. Florida Department of Transportation. Tallahassee, FL. March 2010. 162 pages.

Appendix A

g/C estimation equations for unsignalized intersection analysis in ARTPLAN

Introduction

ARTPLAN currently does not include the Highway Capacity Manual (HCM) analysis methodology for unsignalized intersections. However, in order to still accommodate the presence of unsignalized intersections along an otherwise signalized arterial, very simple equations for estimating an equivalent g/C ratio for an unsignalized intersection were included in previous versions of the Q/LOS Handbook. These equations and the corresponding guidance for analyzing unsignalized intersections in ARTPLAN as given in the 2002 Q/LOS Handbook is as follows.

Two-way and all-way stop control guidance

When using the Generalized Tables, an intersection with a stop sign for the through movement is considered a "signalized intersection" for all roadway types, except "other signalized roadways". The intersection must be signalized to be considered an "other signalized roadway". The following guidelines are offered when applying ARTPLAN to two-way and all-way stop control conditions on arterials:

- **For two-way stop control** in which the arterial traffic is stopped by a stop sign or flashing red light, the equivalent cycle length should be assumed to be 30 seconds with actuated control and arrival type 3. The effective green time ratio, g/C should be computed as:

$$g/C = 1 - (1400/V_c)$$

Where V_c = the sum of the cross street hourly volumes.

- **For all-way stop control** where both the arterial and cross street are stopped, the equivalent cycle length should be set at 15 seconds with actuated control and arrival type 3. The effective g/C ratio should be estimated as:

$$g/C = (15(V_{AH} / V_{CH}) - 3) / 15$$

Where V_{AH} = the arterial volume in the heaviest direction
And V_{CH} = the cross street volume in the heaviest direction

These g/C values are subject to minimum and maximum values of 0.3 and 0.7, respectively.

If the approximations suggested above indicate that the intersection in question would operate beyond its capacity, then a more detailed analysis should be conducted using the HCM2000 Chapter 17 methodology for analyzing two-way or all-way stop control.

Figure 16. Excerpt from 2002 Q/LOS Handbook describing methodology for analyzing unsignalized intersections within ARTPLAN

Evaluation of Existing Methodology

Variables given in Figure 16 include:

- g/C – the ratio of the effective green time to the cycle length
- V_C – the sum of the cross street hourly volumes(veh/h)
- V_{AH} – the arterial volume in the heaviest direction(veh/h)
- V_{CH} – the cross street volume in the heaviest direction (veh/h)

Before evaluating the equations in Figure 17, it needs to be pointed out that there is an error in the two-way stop control equation. In its current form, the equation will yield a g/C value of less than zero for any value of V_C less than 1400. The value of 1400 is intended to represent the level of cross-street volume for which no gaps will be available for the arterial street traffic to use. Thus, the equation was intended to read as

$$g/C = 1 - (V_C/1400) \quad \text{[A-1]}$$

Figure 17 illustrates the relationship between g/C and cross-street volume as given by Eq. A-1.

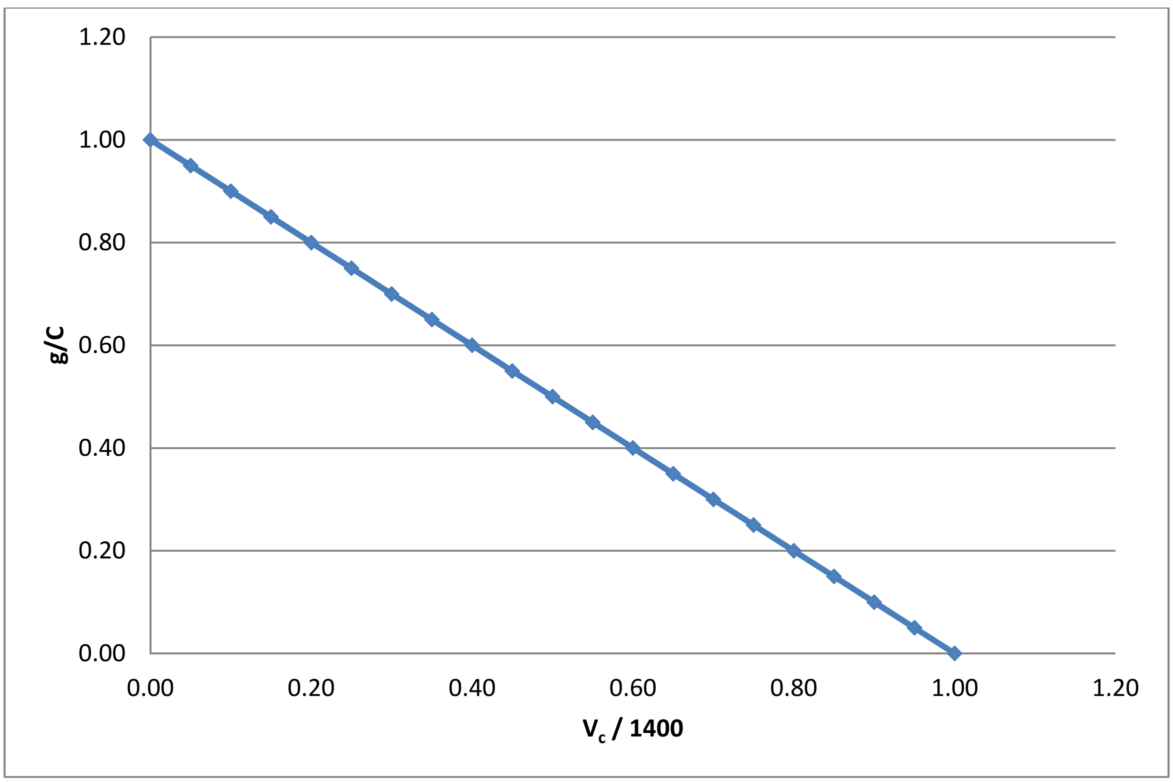

Figure 17. Relationship of g/C to cross street volume for a two-way stop controlled intersection.

The equation from Figure 1 for all-way stop control is repeated as follows

$$g/C = (15\times(V_{AH}/V_{CH}) - 3) / 15 \quad \text{[A-2]}$$

Figure 18 illustrates the relationship between *g*/*C* and the ratio of arterial volume and cross-street volume (both for heaviest direction) as given by Eq. A-2.

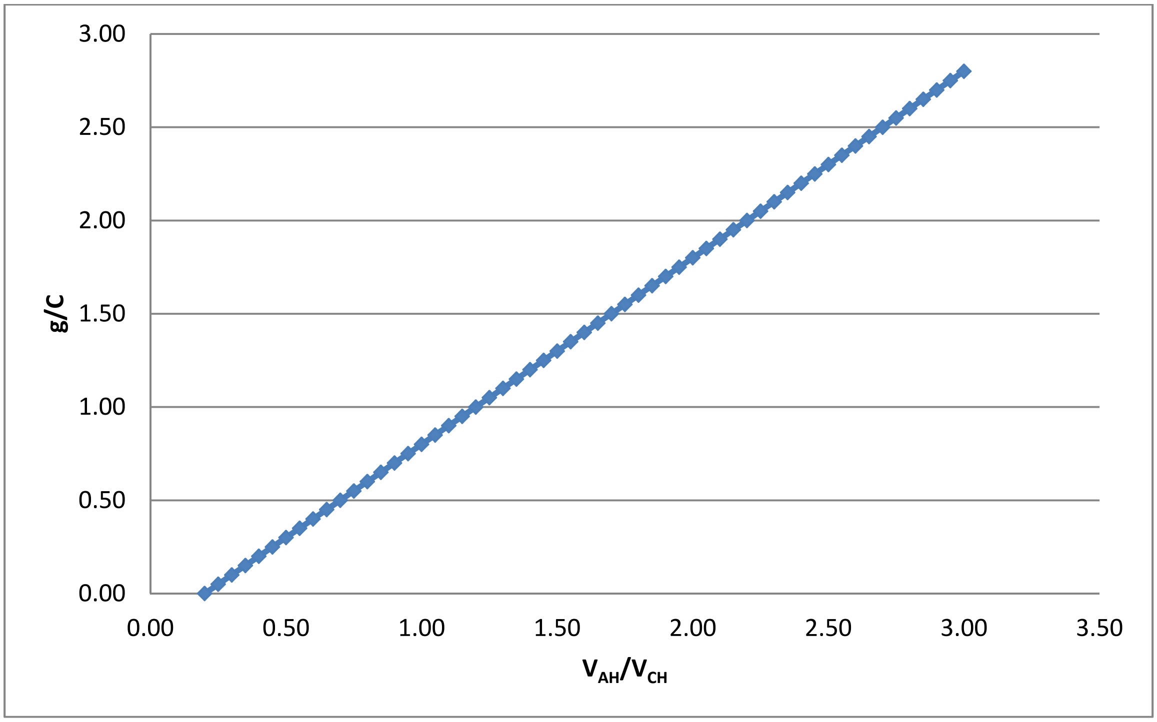

Figure 18. Relationship of *g*/*C* to the ratio of arterial volume and cross-street volume (for heaviest directions) for an all-way stop controlled intersection.

Figure 16 also states that the estimated *g*/*C* values are subject to minimum and maximum values of 0.3 and 0.7, respectively. These limits are rather arbitrary, as the theoretical range for g/C is 0.0 – 1.0. From a practical standpoint, a range of 0.0-1.0 might still be reasonable for the two-way stop control scenario, but for the all-way stop control scenario, the minimum value will be higher than 0.0 since vehicles on each approach will always get their turn to enter the intersection.

For Eq. A-1, the basis for constant value of 1400 is not provided. Also, the volume on the arterial is not explicitly considered—larger arterial volumes will lead to larger delays for the arterial movement, regardless of the cross-street volume. For Eq. A-2, using just the ratio between the arterial volume and cross-street volume is also not sufficient for ultimately deriving a delay value for the arterial street traffic. For example, there will clearly be a large difference in delay for the case of 200 veh/h on both the arterial and cross streets versus 800 veh/h on both the arterial and cross streets. However, Eq. 2 will provide the same *g*/*C* value in both cases. Thus, this equation should not only account for the relative traffic volume on the two streets, but also the absolute traffic volume on each street.

Furthermore, neither equation explicitly accounts for the presence of a left-turn bay. The lack of a left-turn bay at a two-way stop-controlled intersection can have a significant impact on delay if left turns are allowed at the intersection. In this case, left-turn vehicles will be served from the same lane as through (and possibly right-turn) vehicles and will add to the overall delay experienced by the through vehicles. The presence of a left-turn bay at an all-way stop-controlled intersection will also reduce the delay experienced by through vehicles, although not to the extent as that at two-way stop-controlled intersections. The presence of a left-turn bay and the percentage of left turns should be incorporated into these equations, or possibly as a factor in separate equations.

Clearly, improvements can be made to these equations that will ultimately provide better estimates of the delay experienced at unsignalized intersections along the arterial, for the through arterial movement. The research approach used to accomplish this objective is described in the next section.

Research Approach

Obviously, one of the best ways to calculate delays at unsignalized intersections is to apply the unsignalized intersection analysis methodology of the Highway Capacity Manual. However, implementing this procedure into the ARTPLAN software would be a major undertaking. The intent of this task was to improve upon the existing equations given in the 2002 Q/LOS Handbook for unsignalized intersections with a much smaller effort than that required to implement the full HCM analysis methodology.

The general research approach used in accomplishing this task was to analyze an unsignalzed intersection with the given traffic characteristics (with the full unsignalized intersection analysis methodology), and then finding the corresponding g/C value for a signalized intersection with the same geometric and traffic characteristics, that yields same delay as from the unsignalized intersection analysis.

More specifically, the steps involved in this process were as follows:

- Use the HCM unsignalized intersection analysis methodology (as implemented in HCS Version 5.5) to calculate the delays for a large number of scenarios with varying traffic volumes and left-turn percentages, as well as with and without a left-turn bay
- Enter the same inputs into ARTPLAN 2009 (Version 7/17/10) as used in the unsignalized analysis
- Iteratively adjust the g/C entry in ARTPLAN until the resultant delay for the intersection is the same as the delay given by the unsignalized analysis

Four different intersection configurations were considered: two-way stop controlled with left-turn bays, all-way stop controlled with left-turn bays, two-way stop controlled with no left-turn bays, and all-way stop controlled with no left-turn bays. Figure 19 through Figure 22 illustrates each of these configurations.

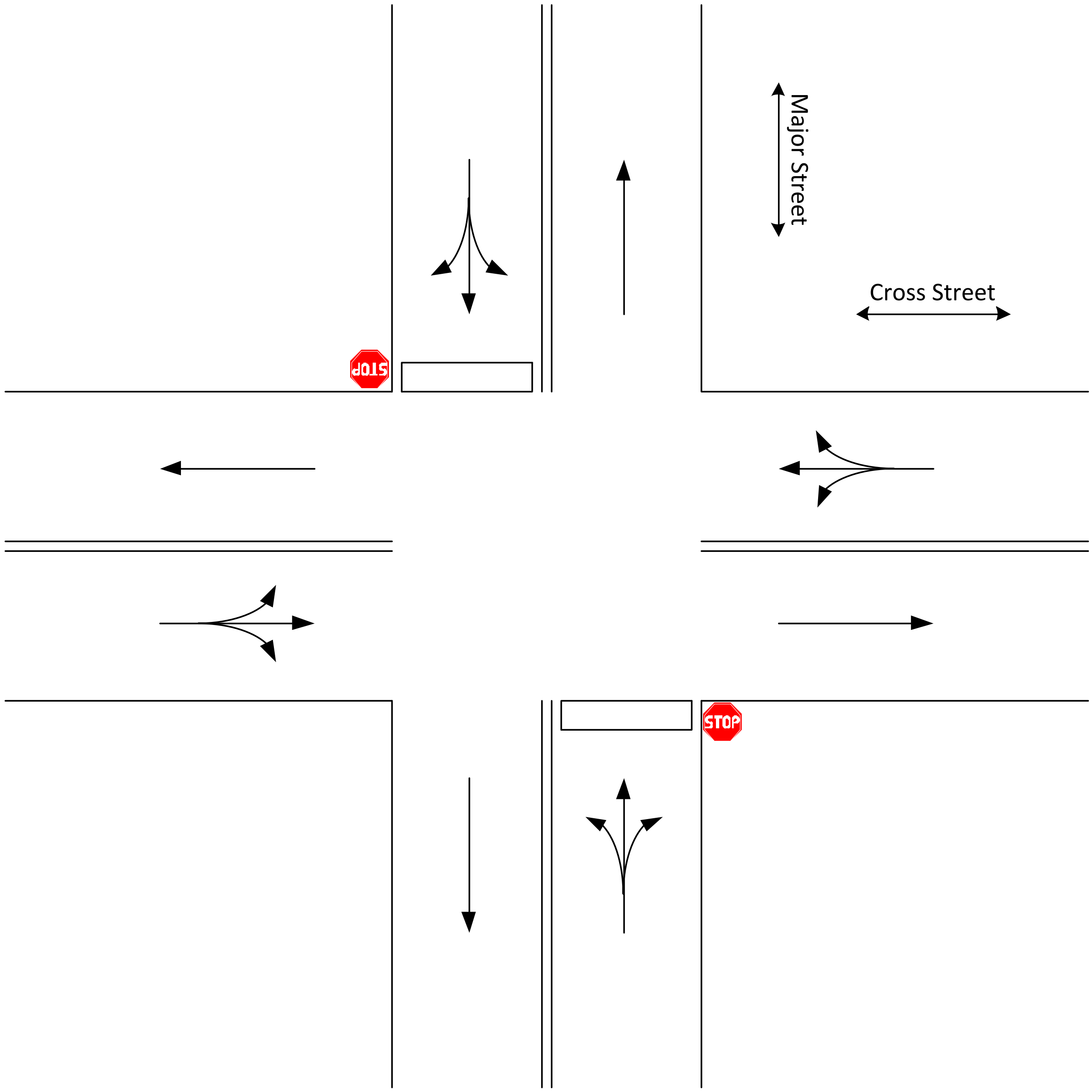

Figure 19. Two-way stop control intersection diagram with no left-turn bays

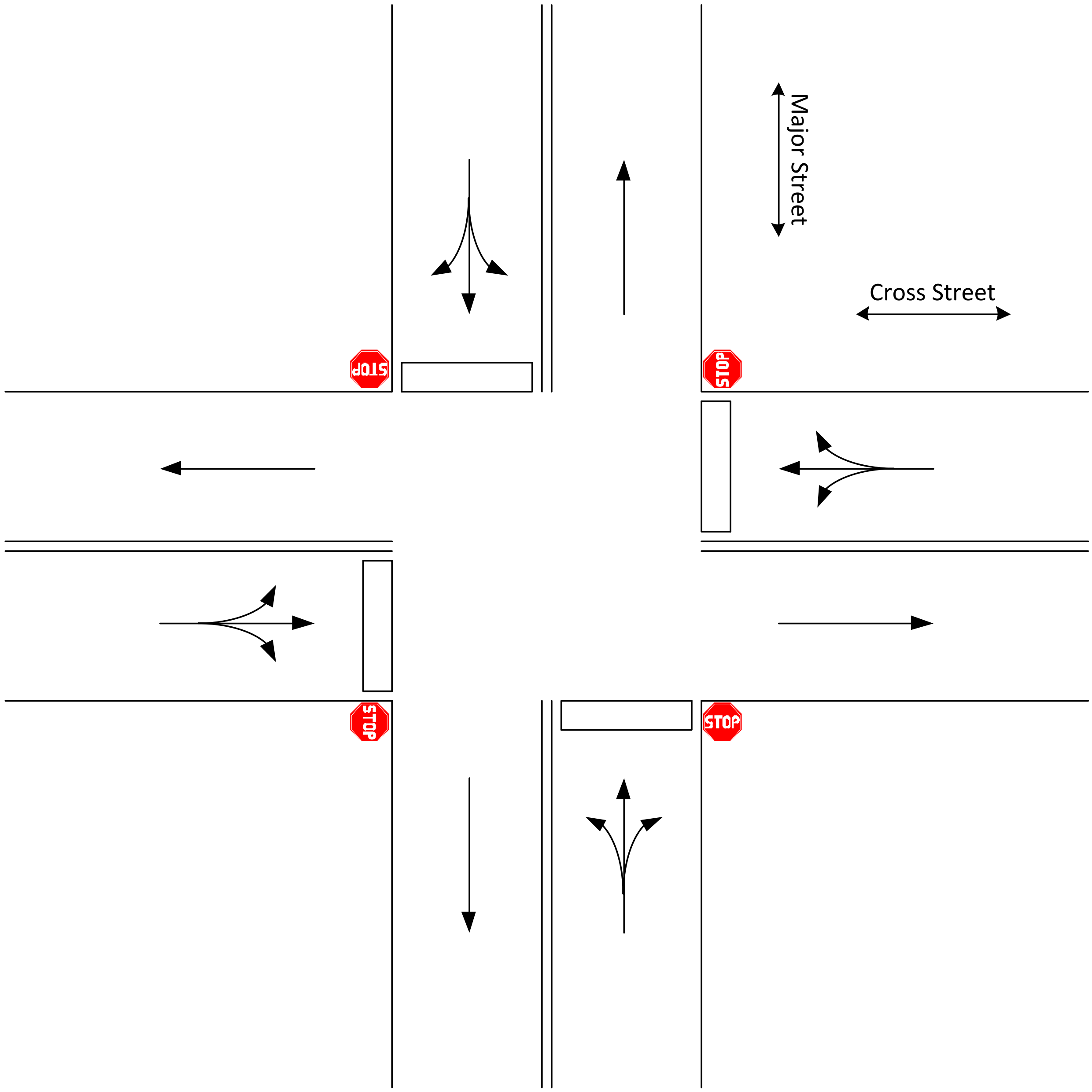

Figure 20. All-way stop control intersection diagram with no left-turn bays

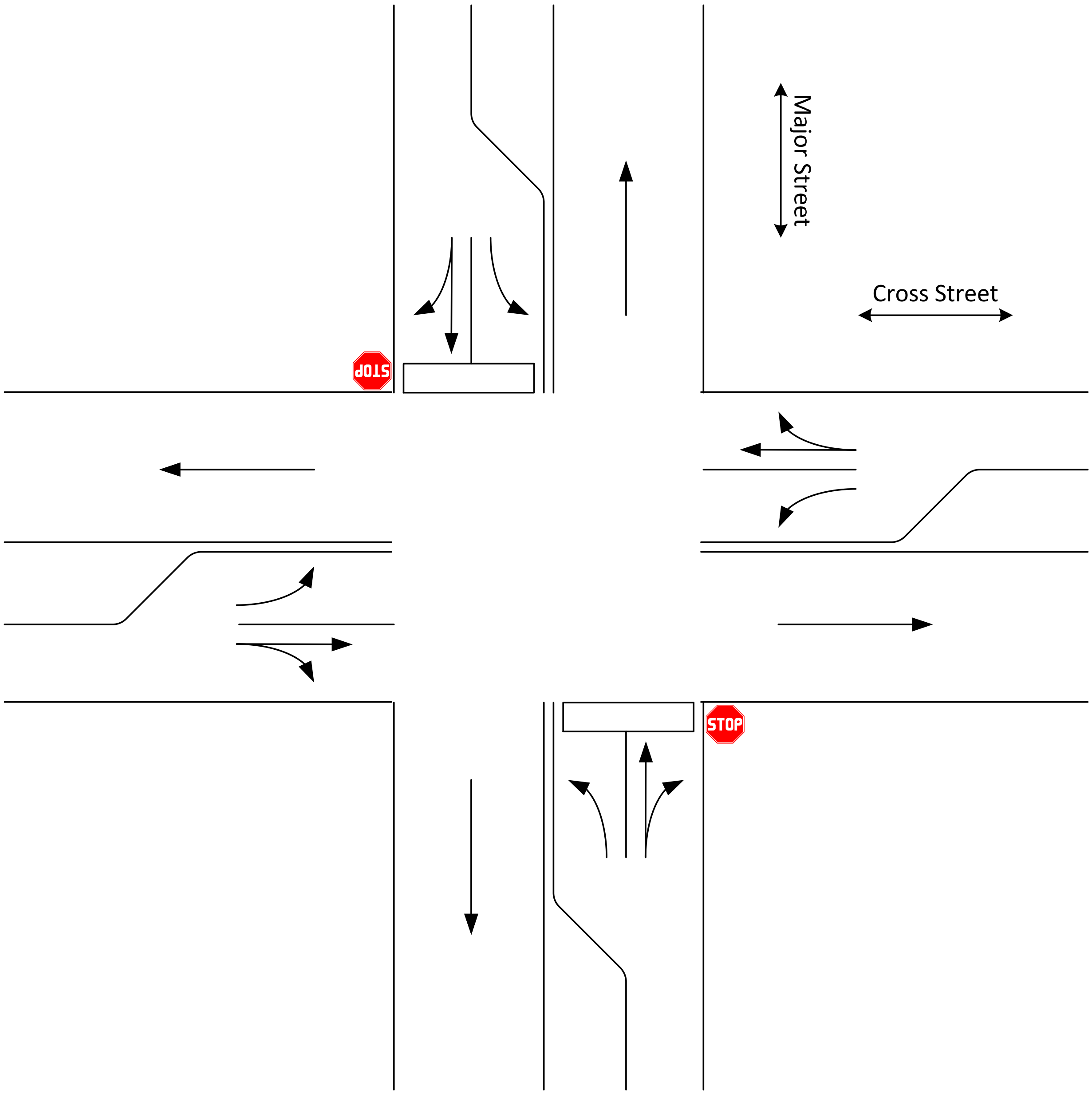

Figure 21. Two-way stop control intersection diagram with left-turn bays

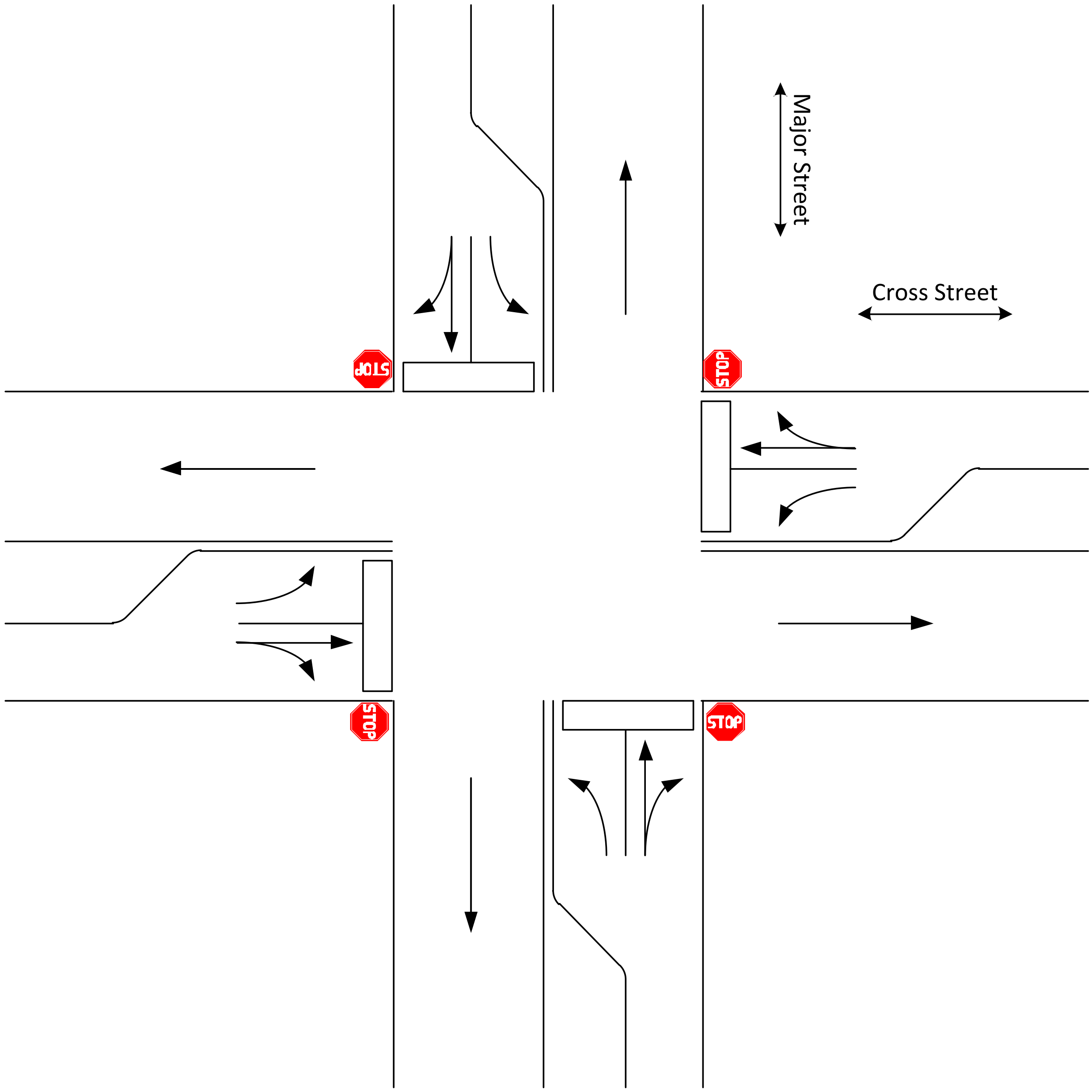

Figure 22. All-way stop control intersection diagram with left-turn bays

Stop-controlled left-turning vehicles require a larger critical headway than thru or right-turning vehicles. Thus, for the situation with no left-turn bays, the left-turning vehicles will lead to increased delay for the through vehicles, which in turn leads to a lower *g*/*C* value.

For the scenarios without left-turn bays, all traffic (left turning, thru, and right turning) in a direction share a single lane. The other scenarios have left turn bays, and allow for left-turning vehicles their own lane, while right turning and thru traffic share the other lane. All four scenarios only have a single through/right-turn lane in each direction. Multiple-lane arterials were not included in this analysis because additional lanes were determined to not significantly affect the final results. The delays are based on acceptable minimum headways that allow the stop controlled movements to enter the intersection. Figure 19-10 in Chapter 19 in the 2010

HCM shows similar acceptable headway times for one and two through-lane (per direction) configurations.

As discussed in the *Existing Methodology* section, the g/C ratio was thought to depend on the ratio of hourly traffic volume on the studied arterial to the hourly traffic volume on the cross street (V_{ah}/V_{ch}). Therefore, the range of volumes investigated were different combinations of the volume on the studied arterial and the volume on the cross street whose ratio would result in predetermined values. For two-way stop controlled scenarios, the range for this ratio was 0.3 to 0.8, and for all-way stop controlled scenarios, the range of this ratio was 0.5 to 1.0, with increments of 0.1 for both two-way and all-way stop controlled scenarios. Given that ARTPLAN imposes a minimum AADT of 1000 (approximately 53 veh/h) for a K100 Study Period Type, lower bounds for the range of traffic volumes in the main street direction were 60 or 75 veh/h for two-way stop controlled scenarios, and intervals of 15 veh/h ranging from 150 through 240 veh/h for all-way stop controlled scenarios. The major-street volumes were then incremented by 15 veh/h, with the cross-street volumes calculated using the preset V_{ah}/V_{ch} ratio. These increments were continued for each ratio until a level of service *F* was achieved for any direction of traffic.

Turns were implemented by having a percentage of the total traffic in one direction assigned to either turn left or right. The percentages of turns analyzed were 0, 6, 12, and 18%. The major street and the cross street were analyzed with the same percentage of turns, as well as the same percentage turning right and left. It should be noted that due to rounding (to the nearest integer) of the vehicle volumes, the turn percentages were often not the desired exact integer values. Nonetheless, the actual turning percentage was used in the statistical analysis.

Other inputs were as follows:

- Peak hour factor was set to 1.0
- Critical gap and follow-up time values were left at the HCM default values
- No heavy vehicles
- No pedestrian traffic
- Level terrain

After the initial inputs were fixed for each scenario, the only modifications made in any input fields were to the traffic volumes per lane. The control delay for the thru lane of the major street and the cross street were recorded from the analysis results. Once the control delay for each variation of traffic volume was collected, ARTPLAN files were prepared with initial inputs and settings. Table 1 summarizes the inputs and setup of the ARTPLAN files used for analysis.

Table 1. Artplan initial inputs for the two-way and all-way stop control scenarios.

	No Turns	**Turns**
Properties Tab		
Area Type	Large Urbanized	Large Urbanized
Class	2	2
Modal Analysis	Auto Only	Auto Only
Type of Analysis	Peak Direction	Peak Direction
Study Period	K100	K100
Intersection Tab		
Cycle Length	120	120
Thru g/C	Inputted value	Inputted value
Arrival Type	4	4
# Thru Lanes	1	1
% Left Turns	0	Inputted value
% Right Turns	0	Inputted value
Excl. Left Turn Lane	No	Yes
Number LT Lanes	N/A	1
Left Turn Storage	N/A	235
Left g/C	N/A	0.15
Excl. Right Turn Lane	No	No
Segment (Auto) Tab		
Length	1760	1760
AADT	Inputted value	Inputted value
# of Thru Lanes	1	1
Posted Speed	45	45
Median Type	Restricted	Restricted

Since ARTPLAN only handles signalized intersections, there is no distinction in the inputs for two-way versus all-way stop control. Again, the idea is to find the g/C value in ARTPLAN that yields the same delay as that given by HCS UNSIGNAL for the same geometric and traffic characteristics.

The process begins with inputting the corresponding annual average daily traffic (AADT) of the major street under analysis, which ARTPLAN converts into an adjusted directional hourly volume (veh/h), based on the default K and D values. Once the proper directional hourly volume is achieved, a "guess and check" method is used for obtaining the correct g/C value. The user must input g/C values into the "Intersection" tab, then check the "LOS (Auto)" tab and note the resulting control delay. This process is repeated until the control delay matches, to the thousandth decimal place, that which was produced using HCS UNSIGNAL. Once the control delay matched the HCS UNSIGNAL output, the g/C value was recorded. This step was then repeated until g/C data were gathered for all desired traffic volume combinations.

For each pair of volumes analyzed (major street and cross street), a corresponding *g*/*C* value and an actual value for the percentage of turns were recorded. A non-linear regression analysis was performed on the data to develop a *g*/*C* estimation equation for two-way stop control and one for all-way stop control. The major street volume, the cross street volume, and the percent turns were the independent variables, and the calculated *g*/*C* value was the dependent variable.

Results

The *g*/*C* estimation equations were found to be:

Two-way stop control:

Without Left-Turn Bays

$$\textit{Est. g/C} = 0.556666 + 0.000968 \times \textit{MainStreetVol} - 0.000006 \times \textit{MainStreetVol}^2 + 0.000446 \times \textit{CrossStreetVol} - 0.000003 \times \textit{CrossStreetVol}^2 - 0.413692 \times (\textit{PctLeftTurns}/100) + 0.707765 \times (\textit{PctLeftTurns}/100)^2$$

Adj. $R^2 = 0.9512$

With Left-Turn Bays

$$\textit{Est. g/C} = 0.501495 + 0.000989 \times \textit{MainStreetVol} - 0.000005 \times \textit{MainStreetVol}^2 + 0.000578 \times \textit{CrossStreetVol} - 0.000003 \times \textit{CrossStreetVol}^2 - 0.136783 \times (\textit{PctLeftTurns}/100) + 0.756259 \times (\textit{PctLeftTurns}/100)^2$$

Adj. $R^2 = 0.9812$

All-way stop control:

Without Left-Turn Bays

$$\textit{Est. g/C} = 0.05336429 + 0.00403063 \times \textit{MainStreetVol} - 0.00001033 \times \textit{MainStreetVol}^2 + 0.00136678 \times \textit{CrossStreetVol} - 0.00000291 \times \textit{CrossStreetVol}^2 + 0.37614667 \times (\textit{PctLeftTurns}/100) - 1.25347703 \times (\textit{PctLeftTurns}/100)^2$$

Adj $R^2 = 0.9408$

With Left-Turn Bays

$$\textit{Est. g/C} = 0.637963 + 0.000971 \times \textit{MainStreetVol} - 0.000004 \times \textit{MainStreetVol}^2 - 0.000440 \times \textit{CrossStreetVol} + 0.0000000424 \times \textit{CrossStreetVol}^2 + 0.140119 \times (\textit{PctLeftTurns}/100) + 1.196012 \times (\textit{PctLeftTurns}/100)^2$$

Adj $R^2 = 0.9033$

Where:

Est. g/C = estimated effective green time to cycle length ratio
MainStreetVol = directional hourly volume on the main street, in veh/h
CrossStreetVol = directional hourly volume, for the heaviest of the two directions, on the cross street, in veh/h
PctLeftTurns = percentage of directional hourly volume on main street turning left

Figure 23 through Figure 26 show scatter plots comparing the *g/C* value calculated with the equations above to the actual *g/C* value obtained using the previously-described process.

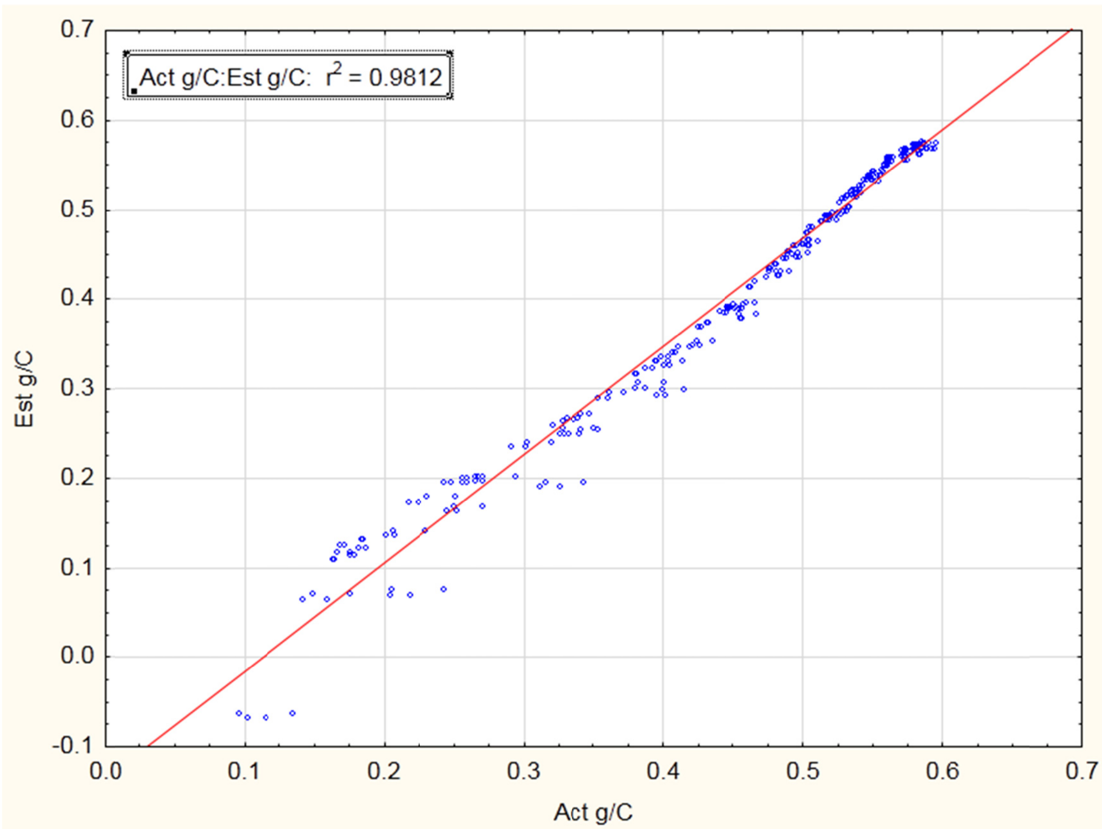

Figure 23. Comparison of actual *g/C* to estimated *g/C* for two-way stop control intersections (with left-turn bays)

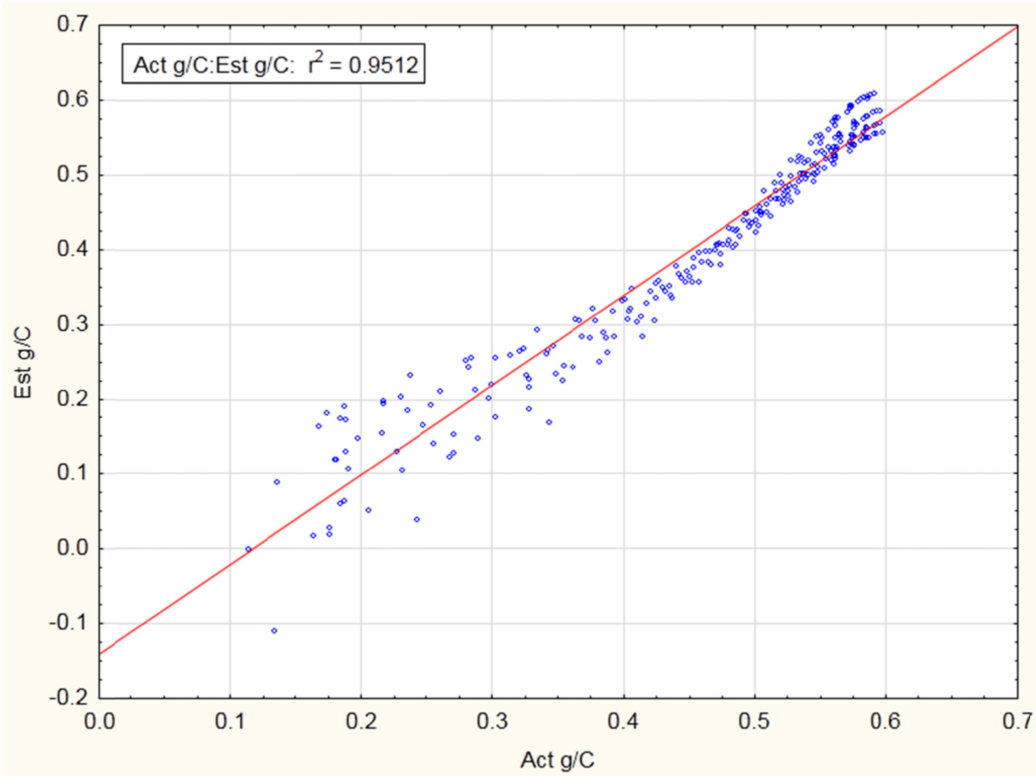

Figure 24. Comparison of actual *g*/*C* to estimated *g*/*C* for two-way stop control intersections (without left-turn bays)

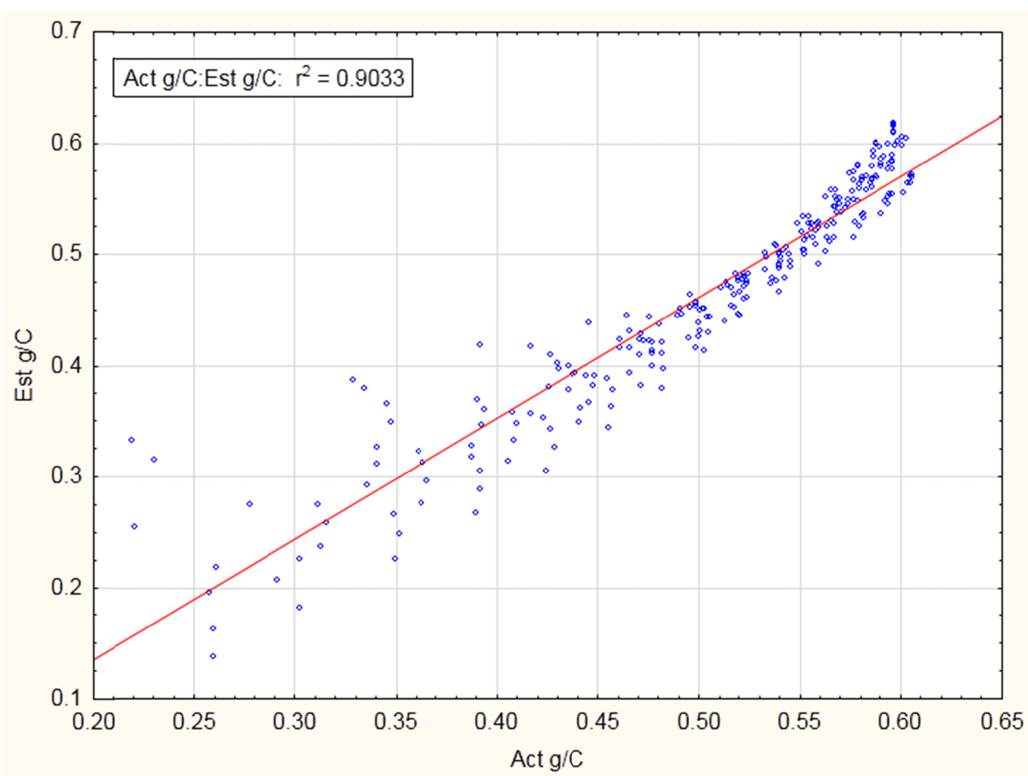

Figure 25. Comparison of actual *g*/*C* to estimated *g*/*C* for all-way stop control intersections (with left-turn bays)

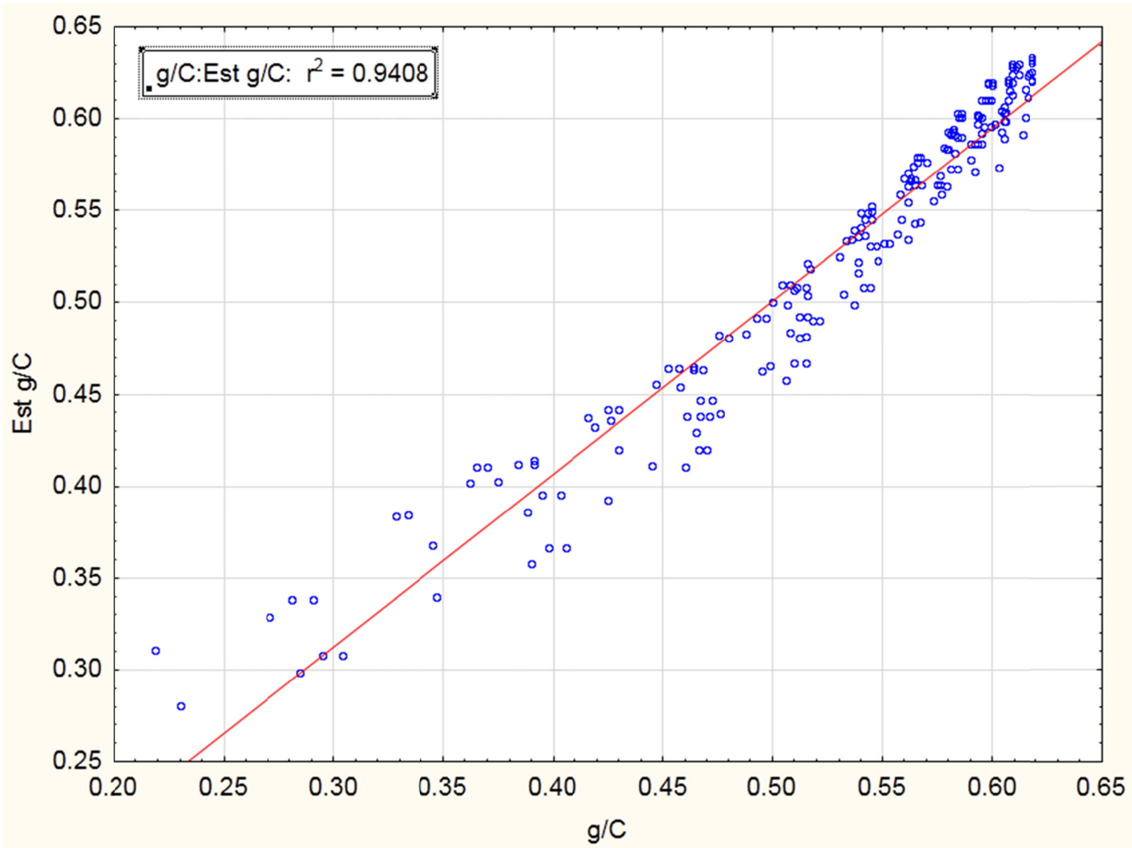

Figure 26. Comparison of actual *g/C* to estimated *g/C* for all-way stop control intersections (without left-turn bays)

As the plots show, the estimation equations are generally more accurate for higher *g/C* ratios, but overall they provide a good fit to the actual *g/C* ratios. Obviously, a g/C value of zero would be assumed for any estimated g/C value of less than zero.

Below is an example calculation using each of the estimation equations.

Two-way stop Control:

Without Left-Turn Bays

Main Street Volume: 180
Cross Street Volume: 225
Percent Left Turns: 12.1%

$$Est.\ g/C = 0.556666 + 0.000968 \times (180) - 0.000006 \times (180)^2 + 0.000446 \times (225) - 0.000003 \times (225)^2 - 0.413692 \times (12.1/100) + 0.707765 \times (12.1/100)^2$$

Est. g/C = 0.445
Actual *g/C* = 0.511

With Left-Turn Bays

Est. g/C = 0.501495 + 0.000989 × (180) – 0.000005 × $(180)^2$ + 0.000578 × (225) – 0.000003 × $(225)^2$ – 0.136783 × (12.1/100) + 0.756259 × $(12.1/100)^2$

Est. g/C = 0.490
Actual *g/C* = 0.523

All-way stop control:

Main Street Volume: 300
Cross Street Volume: 375
Percent Left Turns: 18.1%

Without Left-Turn Bays

Est. g/C = 0.05336429 + 0.00403063 × (300) – 0.00001033 × $(300)^2$ + 0.00136678 × (375) – 0.00000291 × $(375)^2$ + 0.37614667 × (18.1/100) – 1.25347703 × $(18.1/100)^2$

Est. g/C = 0.463
Actual *g/C* = 0.468

With Left-Turn Bays

Est. g/C = 0.637963 + 0.000971 × (300) - 0.000004 × $(300)^2$ – 0.000440 × (375) + 0. 0000000424 × $(375)^2$ + 0.140119 × (18.1/100) + 1.196012 × $(18.1/100)^2$

Est. g/C = 0.475
Actual *g/C* = 0.523

Appendix B

Guidance on *g*/*C* versus Cycle Length Relationship

Introduction

Arterial level of service (LOS) is largely a function of control delay at signalized intersections. Two of the main factors affecting control delay are cycle length and green time. The Florida Department of Transportation (FDOT) implements the arterial analysis procedure from the Highway Capacity Manual (HCM) in its ARTPLAN software. However, since this software is intended for planning and preliminary engineering applications, one simplifying assumption is that the effective green time to cycle length ratio (g/C) is entered directly, rather than individual green, yellow, and all-red times (as is done in the Highway Capacity Software (HCS)).

The effective green time is a function of displayed green time and lost time. Lost time is typically comprised of start-up lost time (such as when the light first turns green) and clearance lost time (such as during the all-red interval). Lost time is typically on the order of 4 seconds per phase. The total lost time, for a given number of phases, is essentially a constant amount, regardless of the cycle length. Thus, for a given number of phases, the lost time will be a larger percentage of the cycle length for shorter cycle lengths. This reduces the amount of effective green time available to traffic movements.

As previously mentioned, the g/C ratio is entered directly into ARTPLAN (it defaults to a value of 0.44). However, if a proper relationship between the g/C ratio and the cycle length is not maintained (e.g., a high g/C ratio but a low cycle length) the resulting control delay estimates will likely be unrealistically optimistic, and consequently the LOS as well.

This paper describes the effort to perform a quantitative comparison of the delay results obtained from HCS and ARTPLAN for cycle lengths ranging from 30 to 240 seconds. It also offers guidance on choosing an appropriate g/C ratio for a given cycle length. The proper selection of a g/C ratio as a function of the cycle length will ensure fidelity of the ARTPLAN results to the HCM results.

Procedure: Illustrate the issue of percentage of lost time relative to cycle length

120 second cycle with constant *g*/*C* ratio

Default values for ARTPLAN

g/C main through $= 0.44$ g/C Main left $= 0.15$ g/C minor through $= 0.22$ g/C minor left $= 0.06$

Total g/C for cycle $= 0.44 + 0.15 + 0.22 + 0.06 = 0.87$

Lost time for cycle $= 16$ seconds (constant for all cycle lengths)

Green time calculations

Green main through $= 120$ seconds $\times 0.44 = 52.80$ seconds

Green main left $= 120$ seconds $\times 0.15 = 18$ seconds

Green minor through $= 120$ seconds $\times 0.22 = 26.40$ seconds

Green minor left $= 120$ seconds $\times 0.06 = 7.21$ seconds

Total green time $= 52.80 + 18 + 25.40 + 7.21 = 104.41$ seconds

Total cycle length $= 104.41 + 16 = 120.41$ seconds

30 second cycle with constant *g*/*C* ratio

Default values for ARTPLAN

g/C main through $= 0.44$ g/C Main left $= 0.15$ g/C minor through $= 0.22$ g/C minor left $= 0.06$

Total g/C for cycle $= 0.44 + 0.15 + 0.22 + 0.06 = 0.87$

Lost time for cycle $= 16$ seconds (constant for all cycle lengths)

Green time calculations

Green main through $= 30$ seconds $\times 0.44 = 13.20$ seconds

Green main left $= 30$ seconds $\times 0.15 = 4.5$ seconds

Green minor through $= 30$ seconds $\times 0.22 = 6.60$ seconds

Green minor left $= 30$ seconds $\times 0.06 = 1.8$ seconds

Total green time $= 13.20 + 4.50 + 6.60 + 1.8 = 26.10$ seconds

Total cycle length $= 26.10 + 16 = 42.10$ seconds (12.10 seconds more than the allotted 30 seconds)

30 second cycle with adjusted *g*/*C* ratios

Default *g*/*C* values for ARTPLAN

g/C main through $= 0.44$ g/C main left $= 0.15$ g/C minor through $= 0.22$ g/C minor left $= 0.06$

g/*C* proportions based on ARTPLAN default *g*/*C* ratios

$\frac{\text{main left}}{\text{main through}} = \frac{0.15}{0.44} = 0.341$ $\frac{minor\ trough}{main\ trough} = \frac{0.22}{0.44} = 0.5$ $\frac{minor\ left}{minor\ trough} \times 2 = \frac{0.06}{0.44} \times 2 = 0.273$

Calculated *g*/*C* values for 30 second cycle

main through $= 0.240$ (set to ensure calculated cycle length does not exceed 30 sec)

main left $=$ main through $\times\ 0.341 = 0.240 \times 0.341 = 0.082$

minor through $=$ main through $\times\ 0.500 = 0.240 \times 0.500 = 0.120$

minor left $=$ minor through $\times\ 0.273 = 0.120 \times 0.273 = 0.033$

Total $g/C = 0.240 + 0.082 + 0.120 + 0.033 = 0.475$

Lost time for cycle $= 16$ seconds (constant for all cycle lengths)

Green time calculations

Green main through $= 30$ seconds $\times\ 0.240 = 7.20$ seconds

Green main left $= 30$ seconds $\times\ 0.082 = 2.46$ seconds

Green minor through $= 30$ seconds $\times\ 0.120 = 3.60$ seconds

Green minor left $= 30$ seconds $\times\ 0.033 = 0.98$ seconds

Total green time $= 7.20 + 2.46 + 3.60 + 0.98 = 14.24$ seconds

Total cycle length $= 14.24 + 16 = 30.24$ seconds (as compared to 30 seconds)

The comparison control delay values (to ARTPLAN's values) for different cycle lengths were obtained by using HCS. HCS allows specific green, yellow, and all-red times to be input. The cycle length is calculated from the input signal interval times, thus maintaining the correct relationship between effective green time and cycle length. Control delay values were computed for cycle lengths ranging from 30 to 120 seconds, using the same demand volume, peak hour factor (PHF), arrival type, start-up lost time, and percent of heavy vehicles for each cycle length. The g/C ratios from both programs were used to determine the amount of time required for each cycle including lost time. The HCS g/C values were determined by adjusting the ratios depending on the cycle length. The default g/C ratios for ARTPLAN were kept at 0.44, and the total cycle lengths were calculated by multiplying the g/C ratios by the assumed cycle lengths.

Results

Table 2 identifies how the *g/C* values were distributed for each HCS scenario and how the corresponding calculated cycle lengths match closely with the assumed cycle lengths.

Table 2. HCS *g/C* ratios and cycle lengths

HCS g/C ratios & Cycle Length										
Cycle (Sec)	30	40	50	60	70	80	90	100	110	120
g/C Main Thru	0.24	0.30	0.34	0.37	0.39	0.41	0.42	0.43	0.43	0.44
g/C Main Left	0.08	0.10	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15
g/C Minor Thru	0.12	0.15	0.17	0.19	0.20	0.20	0.21	0.21	0.22	0.22
g/C Minor Left	0.03	0.04	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06
Total g/C	0.47	0.60	0.68	0.73	.77	0.80	0.82	0.84	0.86	0.87
green Main Thru (Sec)	7.2	12.2	17.2	22.3	27.4	32.4	37.4	42.5	47.6	52.8
Green Main Left (Sec)	2.5	4.1	5.9	7.6	9.3	11.0	12.8	14.5	16.2	18.0
Green Minor Thru (Sec)	3.6	6.1	8.6	11.1	13.7	16.2	18.7	21.3	23.8	26.4
Green Minor Left (Sec)	1.0	1.7	2.3	3.0	3.7	4.4	5.1	5.8	6.5	7.2
Total green (Sec)	14.2	24.0	34.0	44.0	54.1	64.1	74.0	84.0	94.2	104.4
Total Lost Time (Sec)	16	16	16	16	16	16	16	16	16	16
Lost Time % of Cycle	53.3%	40.0%	32.0%	26.7%	22.9%	20.0%	17.8%	16.0%	14.5%	13.3%
Cycle (Sec)	30.2	40.0	50.0	60.0	70.1	80.1	90.0	100.0	110.2	120.4

For HCS, because the *g/C* ratios for each cycle are directly computed, the control delay values will start to increase once the cycle length gets very short (less than 40 seconds for the given input conditions, as illustrated in the graph below). This is due to the fact that a large portion of the cycle is consumed by the total lost time. The results, shown in Figure 27, are consistent with the typical u-shape curve as illustrated by Webster's formulation for optimal cycle length.

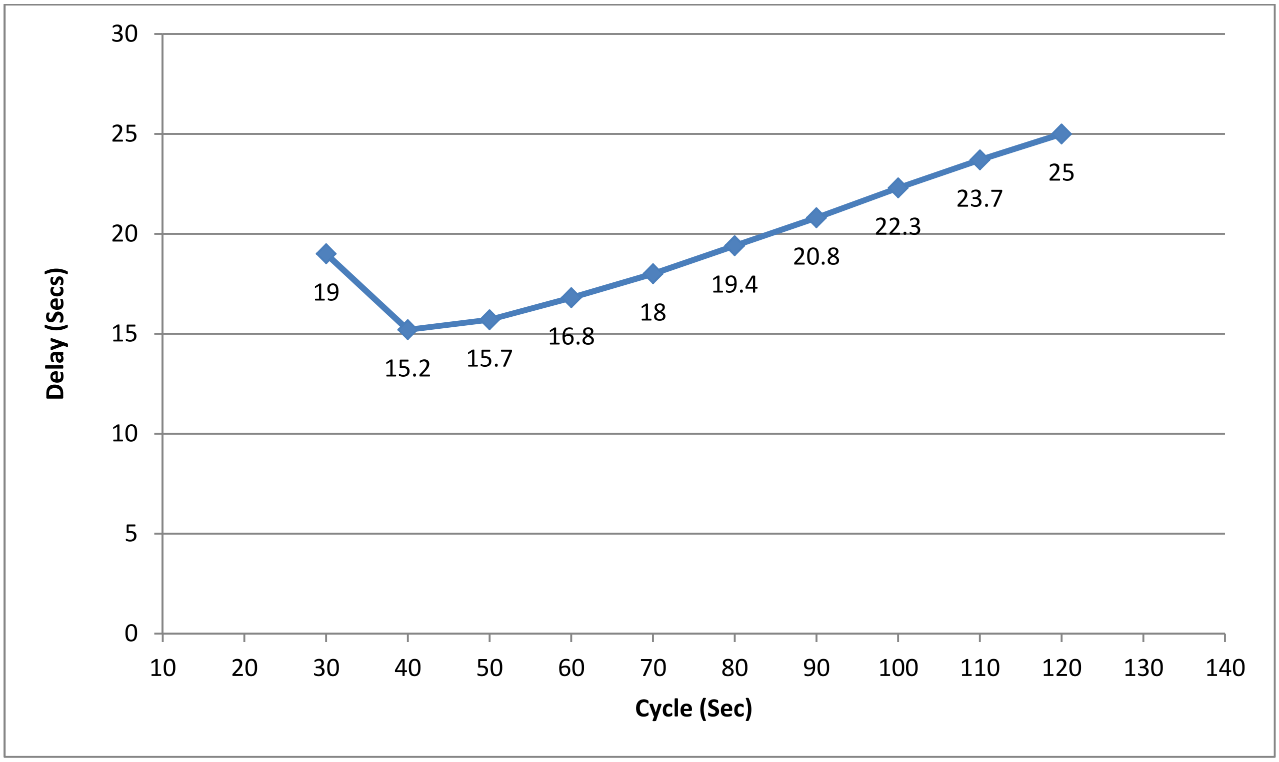

Figure 27. HCS signal delay versus cycle length results, for 0.44 g/C ratio

Table 3 identifies how the *g*/*C* values were distributed for each ARTPLAN scenario. The results show that at a cycle length of 120 seconds, the default *g*/*C* ratios result in the correct cycle length. However, as the cycle length decreases, the difference between the calculated and target cycle length increases. For a cycle length of 30 seconds, there is a difference of 12 seconds between the calculated and target cycle length.

Table 3. ARTPLAN *g/C* ratios and cycle lengths

ARTPLAN g/C ratios & Cycle Length										
Cycle (Sec)	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
g/C Main Thru	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
g/C Main Left	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
g/C Minor Thru	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220	0.220
g/C Minor Left	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
Total g/C	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870	0.870
green Main Thru (Sec)	13.20	17.60	22.00	26.40	30.80	35.20	39.60	44.00	48.40	52.80
Green Main Left (Sec)	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00
Green Minor Thru (Sec)	6.60	8.80	11.00	13.20	15.40	17.60	19.80	22.00	24.20	26.40
Green Minor Left (Sec)	1.80	2.40	3.00	3.60	4.20	4.80	5.41	6.01	6.61	7.21
Total green (Sec)	26.10	34.80	43.51	52.21	60.91	69.61	78.31	87.01	95.71	104.41
Total Lost Time (Sec)	16	16	16	16	16	16	16	16	16	16
Lost Time % of Cycle	53.3%	40.0%	32.0%	26.7%	22.9%	20.0%	17.8%	16.0%	14.5%	13.3%
Cycle (Sec)	42.10	50.80	59.51	68.21	76.91	85.61	94.31	103.01	111.71	120.41

The ARTPLAN control delay results (see Figure 28) show that the control delay will continue to decrease with decreasing cycle length. A significant difference from the HCS results starts to occur at a cycle length of 100 seconds, and as expected the largest deviation is seen at a cycle length of 30 seconds (7.1 vs 19).

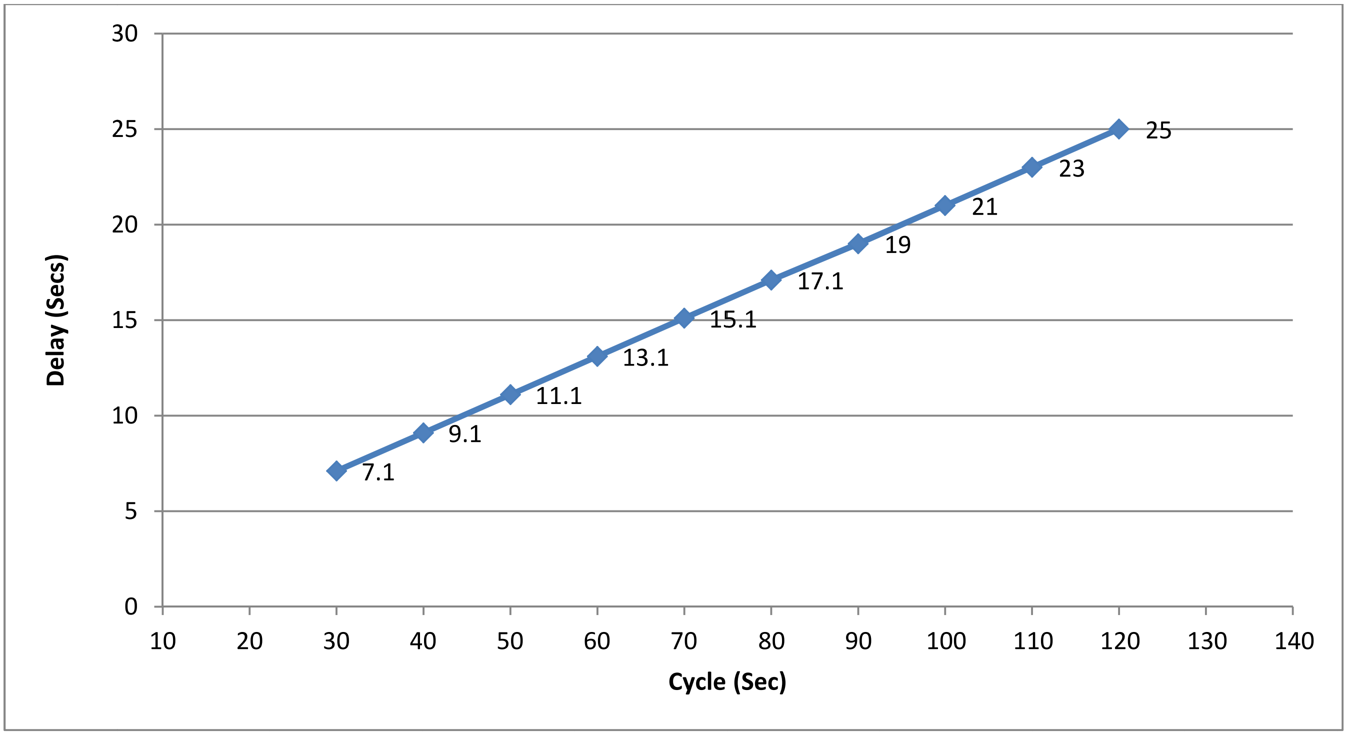

Figure 28. ARTPLAN signal delay versus cycle length results, for 0.44 g/C ratio

When the ARTPLAN *g*/*C* values were replaced with the calculated HCS *g*/*C* ratios, the ARTPLAN control delay values (shown in the figure below) matched closely with the HCS control delay values.

The same analysis was run using a base *g*/*C* ratio of 0.40. The results mirrored those for the base *g*/*C* ratio of 0.44. Because of the similarity of the results, they are presented without any corresponding narrative.

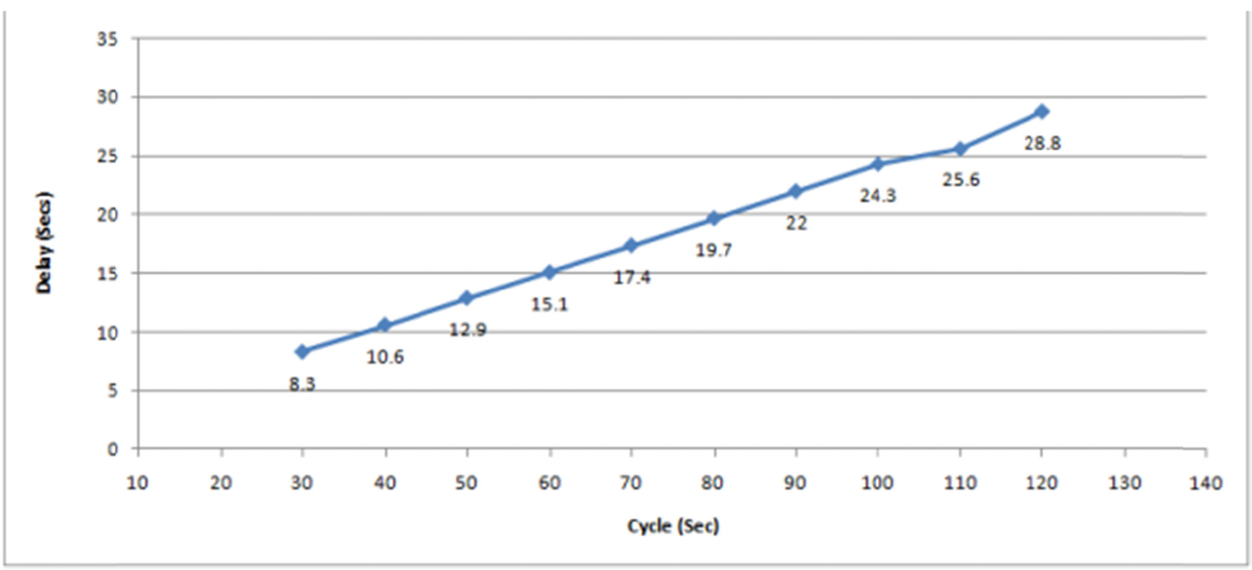

Figure 29. ARTPLAN signal delay versus cycle length results, for 0.40 *g*/*C* ratio

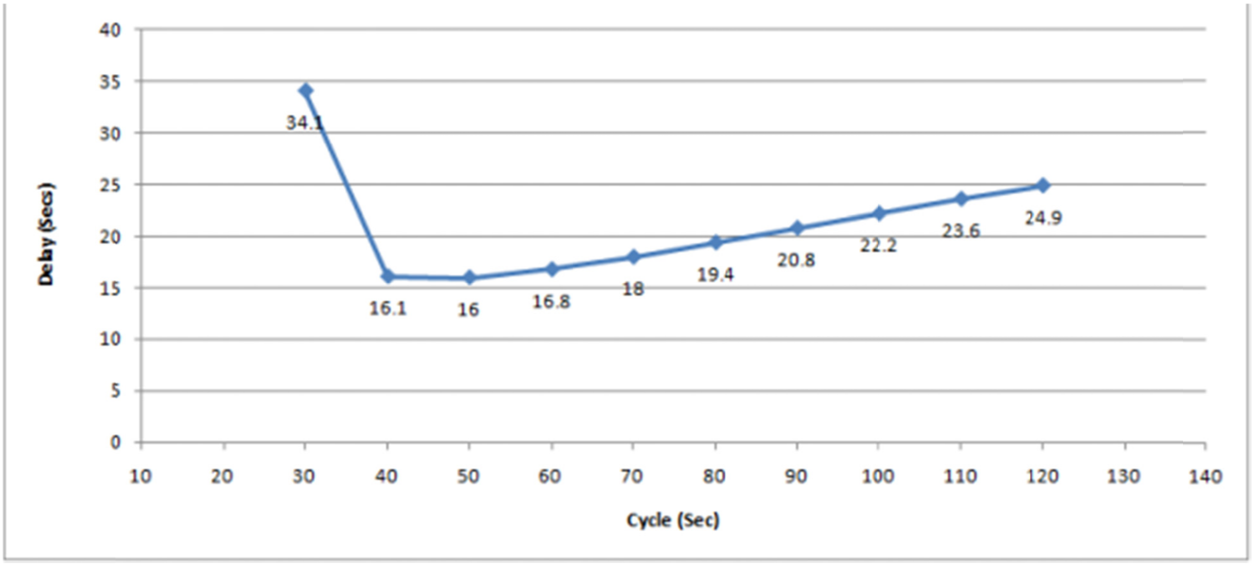

Figure 30. HCS signal delay versus cycle length results, for 0.40 g/C ratio

Again, when the ARTPLAN g/C values were replaced with the calculated HCS g/C ratios, the ARTPLAN control delay values matched closely with the HCS control delay values.

A final analysis was run for a base g/C ratio of 0.48. For this case, the maximum cycle length was extended from 120 to 240 seconds. The same process was followed in order to produce the g/C ratios, and the results are shown below.

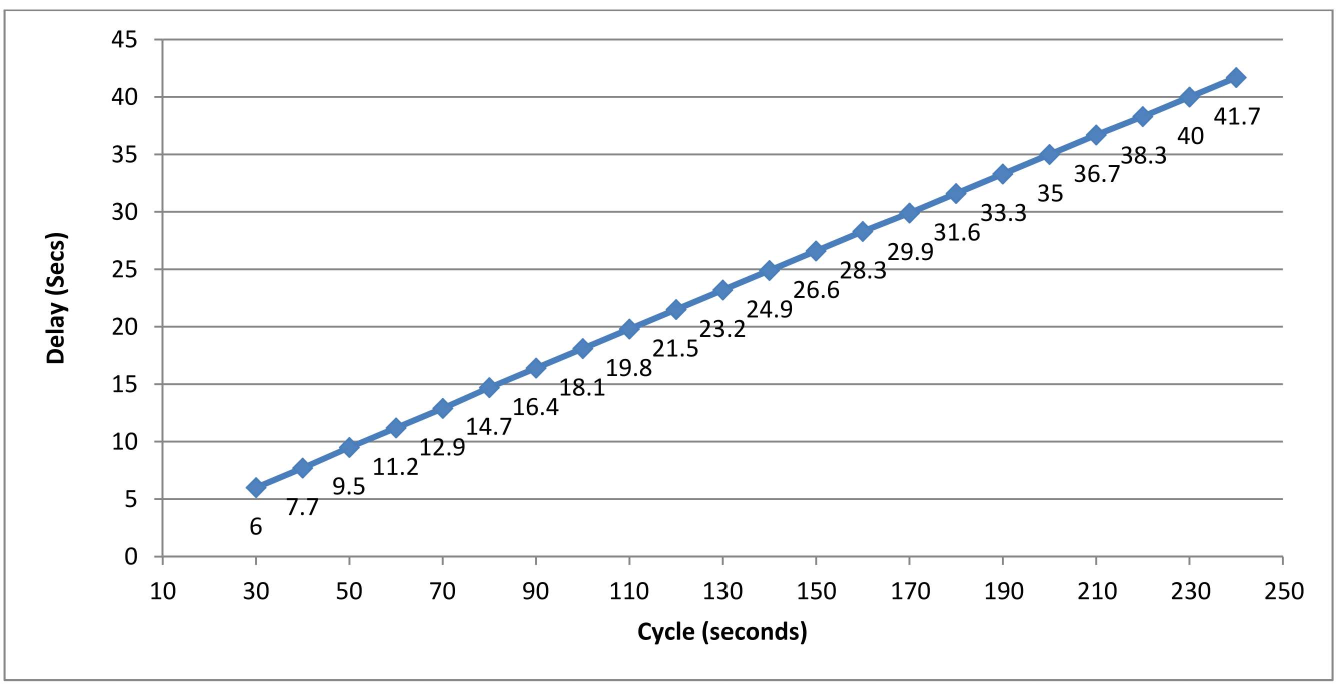

Figure 31. ARTPLAN signal delay versus cycle length results, for 0.48 g/C ratio

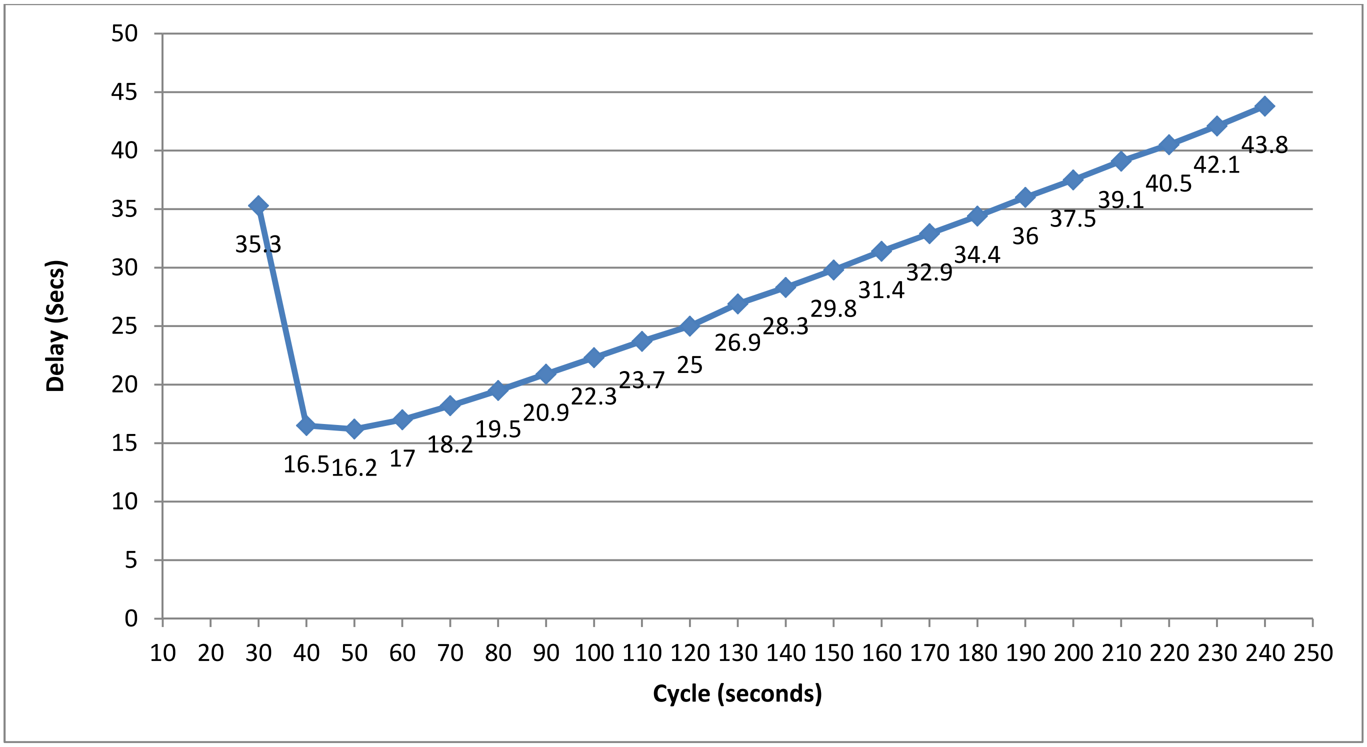

Figure 32. HCS signal delay versus cycle length results, for 0.48 *g*/*C* ratio

The same trends and general relationships apply for the base *g*/*C* of 0.48 as for the base *g*/*C* ratios of 0.44 and 0.40. Again, when the g/C ratios in ARTPLAN were replaced with the calculated HCS *g*/*C* ratios, the ARTPLAN control delay values matched closely with the HCS control delay values.

Recommendations

Using the ARTPLAN default *g*/*C* ratio of 0.44 with any cycle length less than 120 seconds will result in an inaccurate control delay value (likewise for a cycle length less than 240 seconds with a *g*/*C* ratio of 0.48). To ensure that the ARTPLAN calculated control delay values maintain consistency with the HCM, the *g*/*C* values need to maintain a proper relationship with the cycle length values.

Figure 33 illustrates the general relationship between *g*/*C* ratio and cycle length. Also overlaid on this figure is a logarithmic curve fit. The corresponding equation is given by

$$g/C = 0.1005 \times \ln(cycle) - 0.0571 \qquad \text{[B-1]}$$

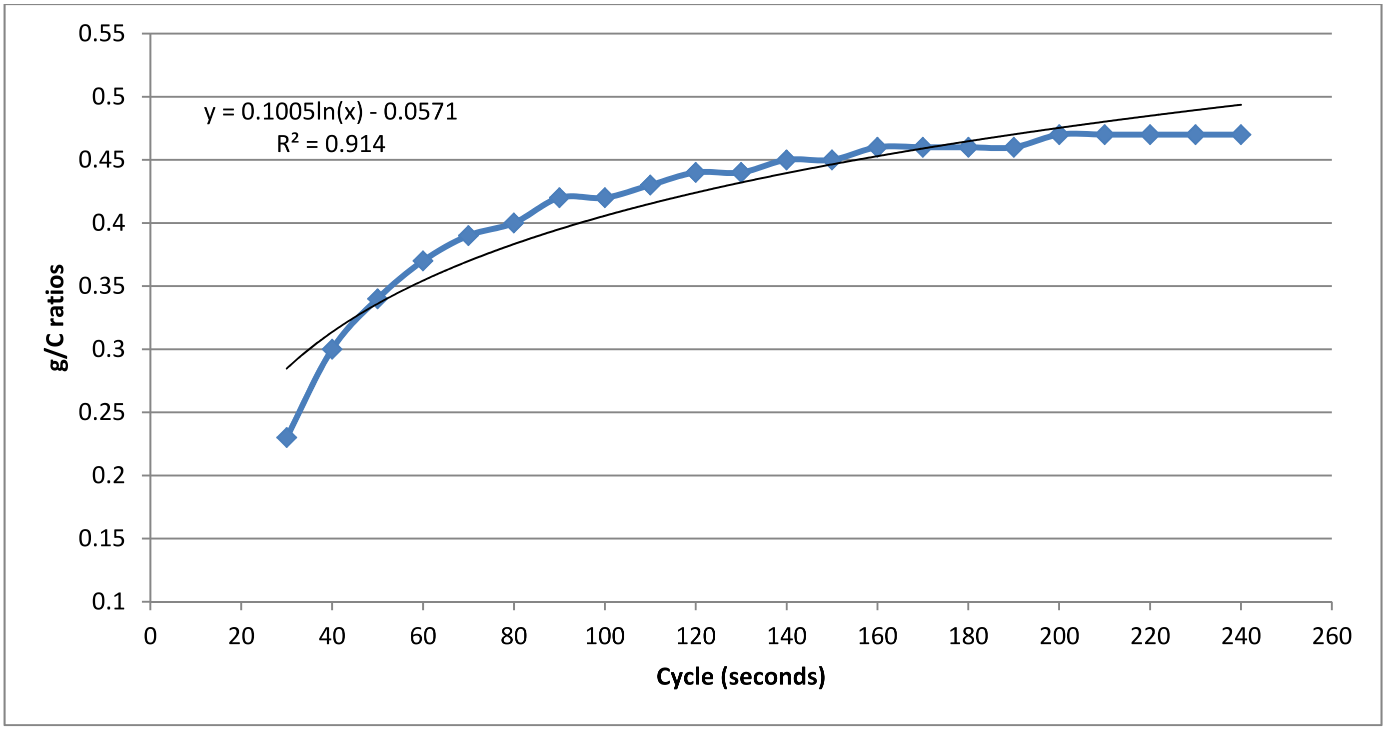

Figure 33. Estimated *g*/*C* values (with single logarithmic function) versus actual *g*/*C* values, as a function of cycle length

The tabular results, for 10-second increments of cycle length, are shown in Table 4.

Table 4. Estimated *g*/*C* values (with single logarithmic function) versus actual *g*/*C* values, as a function of cycle length

Cycle Length	Calculated g/C Values	Estimated g/C Values
30	0.23	0.285
40	0.30	0.314
50	0.34	0.336
60	0.37	0.354
70	0.39	0.370
80	0.40	0.383
90	0.42	0.395
100	0.42	0.406
110	0.43	0.415
120	0.44	0.424
130	0.44	0.432
140	0.45	0.440
150	0.45	0.446
160	0.46	0.453
170	0.46	0.459
180	0.46	0.465
190	0.46	0.470
200	0.47	0.475
210	0.47	0.480
220	0.47	0.485
230	0.47	0.489
240	0.47	0.494

While the logarithmic equation fit is good, it is not great. Another option that will provide comparable results, and is a little simpler to apply, is to fit two linear functions to the data, as shown in Figure 34.

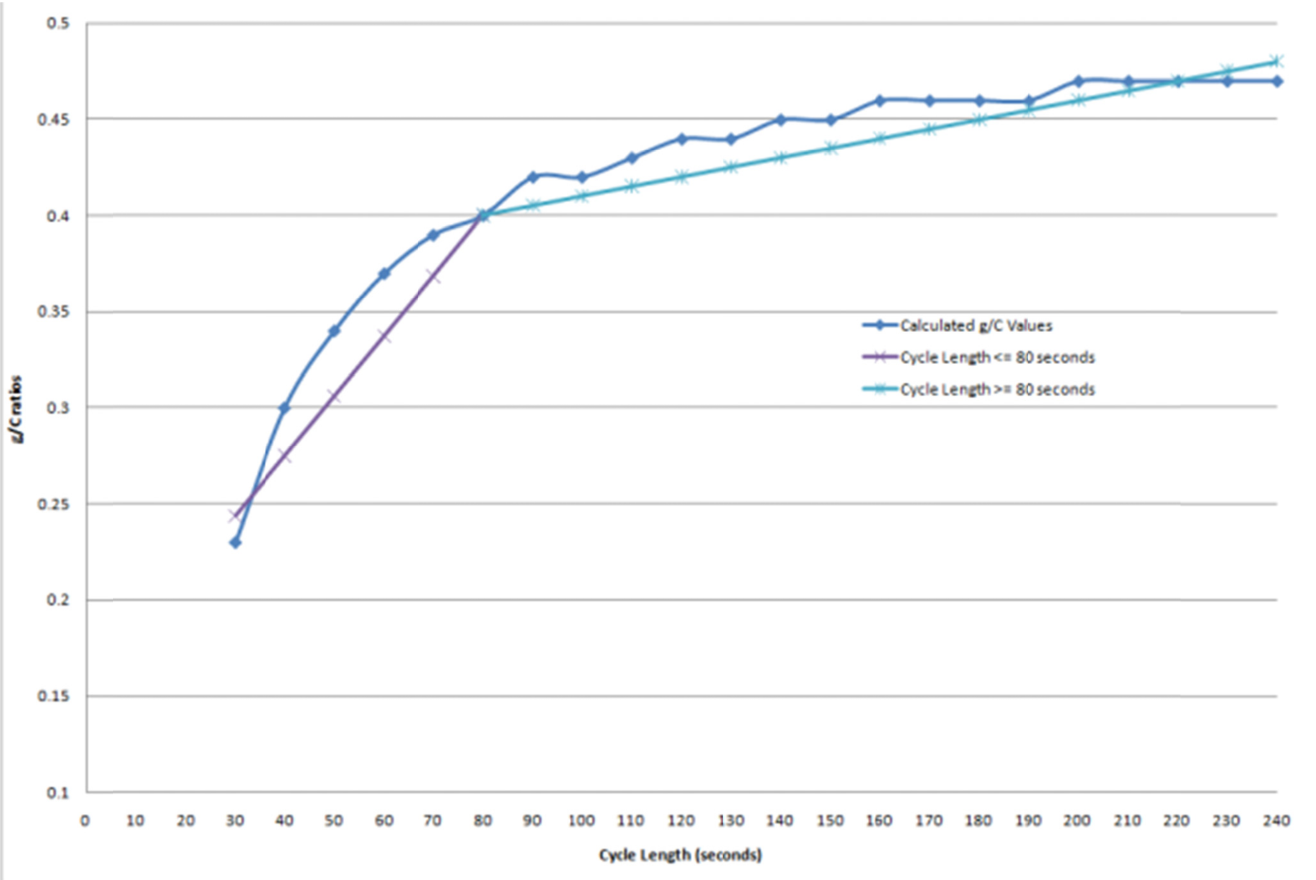

Figure 34. Estimated g/C values (with two linear functions) versus actual g/C values, as a function of cycle length

The common point for the two linear functions is 80 seconds, as this is the point where there is a significant change in slope. The corresponding equations are given by

$$\frac{g}{C} = \begin{cases} 0.00312 \times cycle + 0.15 & if\ cycle < 80\ seconds \\ 0.40 & if\ cycle = 80 seconds \\ 0.0005 \times cycle + 0.36 & if\ cycle > 80\ seconds \end{cases} \qquad \text{[B-2]}$$

The tabular results, for 10-second increments of cycle length, are shown in Table 5.

Table 5. Estimated *g*/*C* values (with two linear functions) versus actual *g*/*C* values, as a function of cycle length

Cycle Length	Calculated g/C Values	Estimated g/C Values
30	0.23	0.244
40	0.30	0.275
50	0.34	0.306
60	0.37	0.337
70	0.39	0.368
80	0.40	0.400
90	0.42	0.405
100	0.42	0.410
110	0.43	0.415
120	0.44	0.420
130	0.44	0.425
140	0.45	0.430
150	0.45	0.435
160	0.46	0.440
170	0.46	0.445
180	0.46	0.450
190	0.46	0.455
200	0.47	0.460
210	0.47	0.465
220	0.47	0.470
230	0.47	0.475
240	0.47	0.480

Appendix C

NCHRP 3-70 Multimodal Calculations Update

User Inputs

$AreaType := 1$

$AADT_1 := 43250$ $K := 0.095$ $D := 0.55$ $PHF := 0.95$

$Length_1 := 2500$	Link length (ft)
$\%HV := 2.5$	Percent Heavy Vehicles
$SegNumLanes_1 := 3$	Number of lanes on segment in one direction
$FFS_1 := 50$	Free-Flow Speed (mi/h)
$Cycle_1 := 120$	Cycle length (sec)
$gC_1 := 0.50$	Main street thru g/C ratio
$ArrivalType_1 := 4$	
$\%RightTurns_1 := 8$	Percent right turns
$MedianType_1 := 1$	0 = None, 1 = Non-Restrictive, 2 = Restrictive
$IntThruLanes_1 := 3$	Number of intersection thru lanes
$LeftTurnBay_1 := 1$	0 = No, 1 = Yes
$W_{outln_1} := 12$	0 = Narrow, 1 = Typical, 2 = Wide, or specific width in ft
$ShoulderBikeLn_1 := 1$	0 = No, 1 = Yes
$PvtCond_1 := 1$	0 = Non-desirable, 1 = Typical, 2 = Desirable
$Sidewalk_1 := 1$	0 = No, 1 = Yes
$SwRdwySep_1 := 1$	0 = Adjacent, 1 = Typical, 2 = Wide
$SwRdwyBar_1 := 1$	0 = No barrier, 1 = Continuous barrier (at least 3' high) or elements (at least 3' high) spaced less than 20 ft apart
$OnStreetParking := 1$	0 = No, 1 = Yes
$ParkingActivity := 2$	0 = Not Applicable, 1 = Low, 2 = Medium, 3 = High
$BusFrequency_1 := 2$	buses/hour
$F_1 := .85$	average bus passenger load factor
$Amenities_1 := 3$	1 - Poor (No bench or shelter) 2 - Fair (Bench only) 3 - Good (Some shelter, some bench) 4 - Excellent (All Shelter)
$NearSideStop := 1$	New input; 0 = bus does not stop before intersection, 1 = bus does stop before intersection

Calculated or Assumed Inputs

$HourlyDirVol_1 := round(AADT_1 \cdot K \cdot D)$ $HourlyDirVol_1 = 2260$ Auto Directional Hourly Volume (veh/h)

$$MajorStreetFlowRate_1 := \frac{HourlyDirVol_1}{PHF} = 2378.9$$

$IntWidth := 60$ From running time calculation

$SegLength_1 := Length_1 + IntWidth = 2560.0$ ft

$NumAccessPts := 3.79$ From running time calculation Number of access points in peak direction; based on link length

$RunningTime := 45.39$ sec From running time calculation

$$SegAutoRunningSpd := \frac{3600}{5280} \cdot \frac{SegLength_1}{RunningTime} = 38.5$$

Segment auto running speed; does not include control delay (mi/h)

$R_{p_1} := 1.333$ From signal delay calculations Platoon ratio

$\%Green_1 := 0.667$ From signal delay calculations Percent arrivals on green

$ParkStripes := 1$ 0 = Parking spots not striped, 1 = Parking spots are striped (assumed for all on-street parking scenarios)

$CrossStreetSpeed := FFS_1 - 5 = 45$ mi/h (based on T-7F export assumption)

$CrossStreetVol := 50\% \cdot MajorStreetFlowRate_1 \cdot 2 = 2378.9$ veh/h (both directions)

$CrossStreetLanes := \frac{IntWidth}{12}$ $CrossStreetLanes = 5$ total lanes in the cross-street (both directions)

$W_{cd} := IntWidth = 60$ curb-to-curb width of the cross-street (ft)

$g_{walk} := gC_1 \cdot Cycle_1 = 60.0$ sec

$$AvgPedXingWait := \frac{0.5 \cdot (Cycle_1 - g_{walk})^2}{Cycle_1} = 15.0$$

sec Equation 18-67, HCM 2010

$$RTORandPermLT := MajorStreetFlowRate_1 \cdot (1 - \%Green_1) \cdot \frac{\%RightTurns_1}{100} = 63.4$$

Conflicting movement approximation (veh/h)

$NumRTIslands := 0$ # of right-turn channelizing islands

$$p_{pk} := \begin{array}{|l} \text{return } 0 \ \text{ if } OnStreetParking = 0 \\ \text{if } OnStreetParking = 1 \\ \quad \begin{array}{|l} 0.2 \ \text{ if } ParkingActivity = 1 \\ 0.5 \ \text{ if } ParkingActivity = 2 \\ 0.8 \ \text{ if } ParkingActivity = 3 \end{array} \end{array}$$

Proportion of on-street-parking occupied

$p_{pk} = 0.5$

$$W_{ol} := \begin{array}{|l} \text{return } 10 \ \text{ if } W_{outln_1} = 0 \\ \text{return } 12 \ \text{ if } W_{outln_1} = 1 \\ \text{return } 14 \ \text{ if } W_{outln_1} = 2 \\ \text{return } W_{outln_1} \ \text{ otherwise} \end{array}$$

Width of outside lane (ft)

$W_{ol} = 12$

$W_{bl} := 5 \cdot ShoulderBikeLn_1 = 5$ Width of paved outside shoulder (ft)

$W_{os} := W_{bl} = 5$ Width of bike lane (ft)

$$W_A := \begin{array}{|l} out \leftarrow 6 \cdot Sidewalk_1 \ \text{ if } SwRdwySep_1 = 0 \\ out \leftarrow 10 \cdot Sidewalk_1 \ \text{ if } SwRdwySep_1 = 1 \\ out \leftarrow 15 \cdot Sidewalk_1 \ \text{ if } SwRdwySep_1 = 2 \end{array}$$

Available sidewalk width (ft)

$W_{buf} := 2 \cdot Sidewalk_1 = 2$ Width of sidewalk/roadway buffer (ft)

Pedestrian Intersection

$F_w := 0.681 \cdot CrossStreetLanes^{0.514}$ $F_w = 1.557$ Equation 18-69, HCM 2010

$CVol := \frac{RTORandPermLT}{4} = 15.8$ conflicting movements in a 15-min period

$Vol_{xso} := \frac{CrossStreetVol}{4 \cdot CrossStreetLanes} = 118.9$ volume in the outer lane of the cross-street in a 15-min period Equation 18-73, HCM 2010

$F_v := 0.00569 \cdot CVol - NumRTIslands \cdot (0.0027 \cdot Vol_{xso} - 0.1946)$ $F_v = 0.09$ Equation 18-70, HCM 2010

$F_s := 0.00013 Vol_{xso} \cdot CrossStreetSpeed$ $F_s = 0.696$ Equation 18-71, HCM 2010

$F_{delay} := 0.0401 \cdot \ln(AvgPedXingWait)$ $F_{delay} = 0.109$ Equation 18-72, HCM 2010

$PedIntScore := 0.5997 + F_w + F_v + F_s + F_{delay}$ $PedIntScore = 3.052$ Equation 18-68, HCM 2010

Pedestrian Link (i.e., "segment" in ARTPLAN)

$$f_b := \begin{vmatrix} \text{return } 5.37 \text{ if } SwRdwyBar_1 = 1 \\ \text{return } 1.0 \text{ if } SwRdwyBar_1 = 0 \end{vmatrix}$$ $f_b = 5.37$ Buffer area coefficient

$$W_t := \begin{vmatrix} \text{return } (W_{ol} + W_{bl} + W_{os}) \text{ if } p_{pk} = 0 \\ \text{return } (W_{ol} + W_{bl}) \text{ if } p_{pk} \neq 0 \end{vmatrix}$$ $W_t = 17.0$ Total width of outside through lane, bicycle lane, and shoulder (ft)

$$W_v := \begin{vmatrix} \text{return } W_t \text{ if } MajorStreetFlowRate_1 > 160 \vee MedianType_1 = 2 \\ \text{return } W_t \cdot (2 - 0.005 \cdot MajorStreetFlowRate_1) \text{ otherwise} \end{vmatrix}$$ $W_v = 17.0$ Effective total width of outside through lane, bicycle lane, and shoulder (Exhibit 17-17, HCM 2010)

$$W_1 := \begin{vmatrix} \text{return } (W_{bl} + W_{os}) \text{ if } p_{pk} < 0.25 \vee ParkStripes = 1 \\ (\text{return } 10) \text{ otherwise} \end{vmatrix}$$ $W_1 = 10.0$ Effective width of combined bicycle lane and shoulder (Exhibit 17-17, HCM 2010)

$W_{aA} := \min(W_A, 10) = 10.0$ Adjusted available sidewalk width

$f_{sw} := 6 - 0.3 \cdot W_{aA} = 3.0$ Sidewalk width coefficient

$$F_w := -1.2276 \cdot \ln(W_v + 0.5 \cdot W_1 + 50 \cdot p_{pk} + W_{buf} \cdot f_b + W_{aA} \cdot f_{sw})$$ $F_w = -5.493$

$$F_v := 0.0091 \frac{MajorStreetFlowRate_1}{4 \cdot SegNumLanes_1}$$ $F_v = 1.804$

$$F_s := 4 \cdot \left(\frac{SegAutoRunningSpd}{100}\right)^2$$ $F_s = 0.592$

$$PedLinkScore := 6.0468 + F_w + F_v + F_s$$ $PedLinkScore = 2.95$

Pedestrian Segment (i.e., combination of link and intersection)

$S_{pf} := 3.3$ ft/s — Recommended value for pedestrian free-flow walking speed with > 20% elderly pedestrians.

$D_c := Length_1 \cdot 0.5 = 1250.0$ — worst case, assuming signal with crosswalk on each end of link

$D_d := D_c \cdot 2 = 2500.0$ ft — Equation 17-33 HCM 2010 Diversion distance

$g_{walk\_mi} := gC_1 \cdot Cycle_1 \cdot 0.5 = 30$

$$d_{pc} := \frac{0.5 \cdot \left(Cycle_1 - g_{walk\_mi}\right)^2}{Cycle_1} = 33.8 \quad \text{sec}$$

crossing delay

$$v_p := \frac{80}{60 \cdot 6} = 0.222 \quad \text{ped/ft/min}$$

Equation 17-25 HCM 2010

$$S_p := \left(1 - 0.00078 \cdot v_p^{\ 2}\right) \cdot S_{pf} = 3.3$$

Equation 17-26 HCM 2010 Pedestrian walking speed

$$F_{cd} := \left| \begin{array}{l} out \leftarrow 0.8 \ \text{if} \ \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 200 \wedge SegNumLanes_1 = 1 \wedge MedianType_1 = 2 \\ out \leftarrow 0.9 \ \text{if} \ \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 350 \wedge SegNumLanes_1 \le 2 \wedge MedianType_1 \le 2 \\ out \leftarrow 1.0 \ \text{if} \ \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 550 \wedge SegNumLanes_1 \le 3 \wedge MedianType_1 \le 1 \\ out \leftarrow 1.1 \ \text{if} \ \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 775 \wedge SegNumLanes_1 \le 4 \wedge MedianType_1 \le 1 \\ out \leftarrow 1.2 \ \text{if} \ \frac{MajorStreetFlowRate_1}{SegNumLanes_1} \ge 775 \wedge SegNumLanes_1 \le 4 \wedge MedianType_1 \le 1 \end{array} \right.$$

$F_{cd} = 1.2$ — Roadway crossing difficulty factor assumed values per flow rate, number of lanes and median type. Refer to Equation 17-35 HCM 2010 for comparision

$$PedSegScore := F_{cd} \cdot (0.318 \cdot PedLinkScore + 0.220 \cdot PedIntScore + 1.606)$$

Equation 17-36 HCM 2010

$PedSegScore = 3.858$

Pedestrian perception index

Bicycle Intersection

$W_t := W_{ol} + W_{bl} + OnStreetParking \cdot W_{os}$ $\qquad W_t = 22$

$F_w := 0.0153 \cdot W_{cd} - 0.2144 \cdot W_t$ $\qquad F_w = -3.799$

$F_v := 0.0066 \cdot \dfrac{MajorStreetFlowRate_1}{4 \cdot IntThruLanes_1}$ $\qquad F_v = 1.308$

$BikeIntScore := 4.1324 + F_w + F_v$ $\qquad BikeIntScore = 1.642$

Note: The HCM 2010 provides a method to calculate delay to bicyclists at signalized intersections; however, this delay is not used as a basis for determining LOS.

Bicycle Link (i.e., "segment" in ARTPLAN)

$$W_e := \begin{cases} \max(W_v - 10 \cdot p_{pk}, 0) & \text{if } W_{bl} + W_{os} < 4 \\ \max(W_v + W_{bl} + W_{os} - 20 \cdot p_{pk}, 0) & \text{otherwise} \end{cases}$$

From Exhibit 17-20, HCM 2010

$W_e = 17$ ft

$$PctHV_a := \begin{cases} (50) & \text{if } MajorStreetFlowRate_1 \cdot \left(1 - \dfrac{\%HV}{100}\right) < 200 \wedge \%HV > 50 \\ \%HV & \text{otherwise} \end{cases}$$

From Exhibit 17-20, HCM 2010

$PctHV_a = 2.5$

--- The following calculation is a replacement for the preceding one ---

Calculate the truck factor [per FDOT project # BD-545-81 (PI: Linda Crider)]

$$TF := \begin{cases} out \leftarrow \left(\dfrac{\dfrac{MajorStreetFlowRate_1}{4 \cdot SegNumLanes_1} \cdot \dfrac{\%HV}{100}}{3}\right) \cdot \dfrac{\%HV}{100} & \text{if } \left(\dfrac{MajorStreetFlowRate_1}{4 \cdot SegNumLanes_1}\right) \cdot \dfrac{\%HV}{100} \le 3 \\ out \leftarrow \dfrac{\%HV}{100} & \text{otherwise} \end{cases}$$

$TF = 0.025$

$$v_{ma} := \begin{cases} MajorStreetFlowRate_1 & \text{if } MajorStreetFlowRate_1 > 4 \cdot SegNumLanes_1 \\ (4 \cdot SegNumLanes_1) & \text{otherwise} \end{cases}$$

From Exhibit 17-20, HCM 2010

$v_{ma} = 2378.9$ veh/h

$S_{Ra} := \max(SegAutoRunningSpd, 21)$

From Exhibit 17-20, HCM 2010

$S_{Ra} = 38.45$ mi/h

$$P_c := \begin{cases} \text{return } 4.5 & \text{if } PvtCond_1 = 2 \\ \text{return } 3.5 & \text{if } PvtCond_1 = 1 \\ \text{return } 2.5 & \text{if } PvtCond_1 = 0 \end{cases}$$

From ARTPLAN's existing methodology

$P_c = 3.5$

$F_w := -\ 0.005 \cdot W_e^{\ 2}$ $\qquad F_w = -1.445$

$F_v := 0.507 \cdot \ln\left(\frac{v_{ma}}{4 \cdot SegNumLanes_1}\right)$ $\qquad F_v = 2.682$

$F_s := 0.199 \cdot \left(1.1199 \cdot \ln\left(S_{Ra} - 20\right) + 0.8103\right) \cdot \left(1 + 0.1038 \cdot PctHV_a\right)^2$ $\qquad F_s = 1.286$

$F_{s2} := 0.199 \cdot \left(1.1199 \cdot \ln\left(S_{Ra} - 20\right) + 0.8103\right) \cdot (1 + 10.38 \cdot TF)^2$ $\qquad F_{s2} = 1.286$

$F_p := \frac{7.066}{P_c^{\ 2}}$ $\qquad F_p = 0.577$

$BikeLinkScore := 0.760 + F_w + F_v + F_{s2} + F_p$ $\qquad BikeLinkScore = 3.86$

Bicycle Segment (i.e., combination of link and intersection)

$F_{bi} := 1.0$ signalized intersection

$$BikeSegScore := 0.160 \cdot BikeLinkScore + 0.011 \cdot F_{bi} \cdot e^{BikeIntScore} + 0.035 \cdot \frac{NumAccessPts}{\frac{SegLength_1}{5280}} + 2.85$$

$BikeSegScore = 3.798$

$$LOS(score) := \begin{array}{|l} \text{return "A" if } score \le 2 \\ \text{return "B" if } score \le 2.75 \\ \text{return "C" if } score \le 3.5 \\ \text{return "D" if } score \le 4.25 \\ \text{return "E" if } score \le 5 \\ \text{return "F" if } score > 5 \end{array}$$

LOS(PedIntScore) = "C" $\qquad$ LOS(BikeIntScore) = "A"

LOS(PedLinkScore) = "C" $\qquad$ LOS(BikeLinkScore) = "D"

LOS(PedSegScore) = "D" $\qquad$ LOS(BikeSegScore) = "D"

Transit Link (i.e., "segment" in ARTPLAN)

$F_h := 4.0 \cdot \exp\left(\dfrac{-1.434}{BusFrequency_1 + 0.001}\right)$ $F_h = 1.954$ Equation 17-54 HCM 2010 headway factor

$elast := -0.4$ HCM default value ridership elasticity

$$T_{btt} := \begin{vmatrix} out \leftarrow 6.0 \ \text{ if } AreaType = 1 \\ out \leftarrow 4.0 \ \text{ otherwise} \end{vmatrix}$$

$T_{btt} = 6$ base travel time rate

$$a_1 := \begin{vmatrix} \text{return } 1.0 \ \text{ if } F_l \le 0.8 \\ \text{return } 1 + \dfrac{4 \cdot (F_l - 0.8)}{4.2} \ \text{ if } F_l \le 1.0 \\ \text{return } 1 + \dfrac{4 \cdot (F_l - 0.8) + (F_l - 1.0) \cdot 6.5 + 5 \cdot (F_l - 1.0)}{4.2 \cdot F_l} \ \text{ if } F_l > 1.0 \end{vmatrix}$$

Equation 17-58 HCM 2010

passenger load weighting factor

$a_1 = 1.048$

$t_{late} := 5.0$ min HCM default threshold late time

$p_{ot} := 0.75$ HCM default proportion of transit vehicles arriving in the threshold late time

$t_{ex} := t_{late} \cdot (1 - p_{ot})^2$ $t_{ex} = 1.563$ min Equation 17-59 HCM 2010 excess wait time due to late arrivals

$L_{pt} := 3.7$ mi HCM default average passenger trip length

$T_{ex} := \dfrac{t_{ex}}{L_{pt}} = 0.422$ min/mi excess wait time rate due late arrivals

$$p_{sh} := \begin{vmatrix} \text{return } 0 \ \text{ if } Amenities_1 = 1 \\ \text{return } 0 \ \text{ if } Amenities_1 = 2 \\ \text{return } 0.5 \ \text{ if } Amenities_1 = 3 \\ \text{return } 1 \ \text{ if } Amenities_1 = 4 \end{vmatrix}$$

$p_{sh} = 0.5$

assumed proportion of shelter and proportion of bench values based on input "Amenities".

$$p_{be} := \begin{vmatrix} \text{return } 0 \ \text{ if } Amenities_1 = 1 \\ \text{return } 1 \ \text{ if } Amenities_1 = 2 \\ \text{return } 1 \ \text{ if } Amenities_1 = 3 \\ \text{return } 1 \ \text{ if } Amenities_1 = 4 \end{vmatrix}$$

$p_{be} = 1$

$$T_{at} := \frac{1.3 \cdot p_{sh} + 0.2 \cdot p_{be}}{L_{pt}} \qquad T_{at} = 0.23$$

Equation 17-58 HCM 2010
amenity time rate

$$S_R := \frac{3600 \cdot \mathrm{Length}_1}{5280 \cdot \mathrm{RunningTime}} = 37.553$$

motorized vehicle running speed

$$S_{Rt} := \min\left(S_R, \frac{49}{1 + \exp\left(-3.54 + \frac{1937}{\mathrm{Length}_1}\right)}\right) = 37.553$$

Equation 17-45 HCM 2010
transit vehicle running speed

$$r_{dt} := 0.540 + 0.0698 \cdot S_{Rt} = 3.161$$

Equation 17-48 HCM 2010
transit vehicle deceleration rate

$$r_{at} := 0.540 + 0.0698 \cdot S_{Rt} = 3.161$$

transit vehicle acceleration rate

$$f_{ad} := \left| \begin{array}{l} \text{return } 1.0 \text{ if NearSideStop} = 0 \\ \text{return } gC_1 \text{ if NearSideStop} = 1 \end{array} \right. \qquad f_{ad} = 0.5$$

Slightly revised version of
Equation 17-47 HCM 2010

Proportion of transit vehicle accel/decel
delay not due to traffic control

$$d_{ad} := \left(\frac{5280}{3600}\right) \cdot \left(\frac{S_{Rt}}{2}\right) \cdot \left(\frac{1}{r_{at}} + \frac{1}{r_{dt}}\right) \cdot f_{ad} = 8.712$$

Equation 17-46 HCM 2010
transit vehicle accel/decel delay due to transit stop

$$f_{dt} := \left| \begin{array}{l} \text{return } 1.0 \text{ if NearSideStop} = 0 \\ \text{return } gC_1 \text{ if NearSideStop} = 1 \end{array} \right.$$

proportion of dwell time occuring during effective green

$$t_d := \left| \begin{array}{l} \text{out} \leftarrow 60 \text{ if AreaType} = 1 \\ \text{out} \leftarrow 60 \text{ if AreaType} = 2 \\ \text{out} \leftarrow 30 \text{ if AreaType} = 3 \\ \text{out} \leftarrow 15 \text{ if AreaType} = 4 \end{array} \right. \qquad t_d = 60$$

Exhibit 17-25 HCM 2010

average dwell time

$$d_{ps} := t_d + f_{dt} = 60.5$$

Equation 17-49 HCM 2010
transit vehicle delay due to serving passengers

$$d_{re} := 0$$

Re-entry delay from a bus pull-out. Assume no bus pull-out;

$$d_{ts} := d_{ad} + d_{ps} + d_{re} = 69.212$$

Equation 17-50 HCM 2010
delay due to a transit vehicle stop for passenger
pick-up at stop i within the segment

$$t_{Rt} := \frac{3600 \cdot \mathrm{Length}_1}{5280 \cdot S_{Rt}} + d_{ts} = 114.602$$

Equation 17-44 HCM 2010
segment running time of transit vehicle

$$t_l := \begin{cases} out \leftarrow 3.0 & \text{if AreaType} = 1 \\ out \leftarrow 1.0 & \text{otherwise} \end{cases}$$

$t_l = 3$

Exhibit 17-22 HCM 2010
transit vehicle running time loss

$$d := t_l \cdot 60 \cdot \frac{Length_1}{5280} = 85.227$$

Equation 17-51 HCM 2010
control delay

$$S_{Ttseg} := \frac{(3600 \cdot Length_1)}{5280 \cdot (t_{Rt} + d)} = 8.53$$

Equation 17-52 HCM 2010
travel speed of transit vehicles along the segment

$$T_{ptt} := a_1 \cdot \left(\frac{60}{S_{Ttseg}}\right) + 2 \cdot T_{ex} - T_{at} = 7.984$$

Equation 17-58 HCM 2010
perceived travel time rate

$$F_{tt} := \frac{(elast - 1) \cdot T_{btt} - (elast + 1) \cdot T_{ptt}}{(elast - 1) \cdot T_{ptt} - (elast + 1) \cdot T_{btt}} = 0.893$$

Equation 17-55 HCM 2010
perceived travel time factor

$$S_{w\_r} := F_h \cdot F_{tt} = 1.744$$

Equation 17-53 HCM 2010
transit wait-ride score

$$I_{t\_seg} := 6.0 - 1.5 \cdot S_{w\_r} + PedLinkScore = 6.334$$

Equation 17-60 HCM 2010
transit passenger score for segment

$$SegTransitLOS(I_{t\_seg}) := \begin{cases} \text{return "A"} & \text{if } I_{t\_seg} \le 2 \\ \text{return "B"} & \text{if } I_{t\_seg} \le 2.75 \\ \text{return "C"} & \text{if } I_{t\_seg} \le 3.5 \\ \text{return "D"} & \text{if } I_{t\_seg} \le 4.25 \\ \text{return "E"} & \text{if } I_{t\_seg} \le 5 \\ \text{return "F"} & \text{if } I_{t\_seg} > 5 \end{cases}$$

Exhibit 17-3 HCM 2010

$$SegTransitLOS(I_{t\_seg}) = \text{"F"}$$

Appendix D

NCHRP 3-79 Arterial Segment Free-Flow Speed Calculation Procedure

Inputs

$PostSpd := 45$ mi/h

$NumSegThruLanes := 3$

$LinkLength := 2500$ ft

ARTPLAN's segment length is defined the same as link length in the HCM 2010. In the HCM 2010, link length is equal to segment length minus the upstream intersection width.

$AreaType := 1$ 1 = Large Urbanized, 2 = Other Urbanized, 3 = Transitioning/Urban, 4 = Rural Developed

$$IntWidth := \left| \begin{array}{l} out \leftarrow 60 \ \text{ if } \ AreaType = 1 \\ out \leftarrow 60 \ \text{ if } \ AreaType = 2 \\ out \leftarrow 36 \ \text{ if } \ AreaType = 3 \\ out \leftarrow 24 \ \text{ if } \ AreaType = 4 \end{array} \right.$$

$IntWidth = 60$

$SegLength := LinkLength + IntWidth = 2560$ ft

$AADT := 43250$ $K := 0.095$ $D := 0.55$ $PHF := 0.95$

$HourlyDirVol := (AADT \cdot K \cdot D)$

$$MidSegDemand := \frac{HourlyDirVol}{PHF} = 2378.8 \quad \text{veh/h}$$

$$MidBlockPctTurns := \left| \begin{array}{l} out \leftarrow 8 \ \text{ if } \ AreaType = 1 \\ out \leftarrow 6 \ \text{ if } \ AreaType = 2 \\ out \leftarrow 4 \ \text{ if } \ AreaType = 3 \\ out \leftarrow 2 \ \text{ if } \ AreaType = 4 \end{array} \right.$$

$MidBlockPctTurns = 8$

$MedianType := 1$ 0 = None, 1 = NonRestrictive, 2 = Restrictive

$$PropSegRestrictMed := \left| \begin{array}{l} out \leftarrow 0 \ \text{ if } \ MedianType = 0 \\ out \leftarrow 0 \ \text{ if } \ MedianType = 1 \\ out \leftarrow 1.0 \ \text{ if } \ MedianType = 2 \end{array} \right.$$

Proportion of segment length with restricted median

$PropSegRestrictMed = 0$

$$PropSegWithCurb := \left| \begin{array}{l} out \leftarrow 1.0 \ \text{ if } \ AreaType = 1 \\ out \leftarrow 1.0 \ \text{ if } \ AreaType = 2 \\ out \leftarrow 0.5 \ \text{ if } \ AreaType = 3 \\ out \leftarrow 0.0 \ \text{ if } \ AreaType = 4 \end{array} \right.$$

Proportion of segment length with right-side curb

$PropSegWithCurb = 1.0$

$$NumAccessPts := \begin{vmatrix} out \leftarrow 0 \ \ \text{if} \ \ LinkLength < 660 \\ out \leftarrow 2 \cdot \dfrac{LinkLength}{1320} \ \ \text{if} \ \ LinkLength \geq 660 \end{vmatrix}$$

$NumAccessPts = 3.79$

$NumAccessPtsSubDir := NumAccessPts = 3.79$ — Number of access points in the subject direction

$NumAccessPtsOppDir := NumAccessPts = 3.79$ — For planning purposes, assume opposing direction has same number of access points as subject direction

$OnStreetParking := 1$ — 0 = No, 1 = Yes

$ParkingActivity := 2$ — 0 = Not Applicalbe, 1 = Low, 2 = Medium, 3 = High

$$OtherDelay := \begin{vmatrix} \text{return } 0 \ \ \text{if} \ \ OnStreetParking = 0 \\ \text{if } OnStreetParking = 1 \\ \quad \begin{vmatrix} \text{return } 1.0 \ \ \text{if} \ \ ParkingActivity = 1 \\ \text{return } 3.0 \ \ \text{if} \ \ ParkingActivity = 2 \\ \text{return } 5.0 \ \ \text{if} \ \ ParkingActivity = 3 \end{vmatrix} \end{vmatrix}$$

planning level assumptions

$OtherDelay = 3.0$ sec/veh

$StartUpLostTime := 2.0$ — HCM default; Artplan does not contain an input for startup lost time because effective green time is entered directly (i.e., g/C ratio)

$ControlDelay := 19.11$ — Obtained from signal delay calculation procedure

$$MidSegVolPerLane := \frac{MidSegDemand}{NumSegThruLanes}$$

$MidSegVolPerLane = 792.917$ veh/h/ln

Calculations

$$TurningDelay := \begin{vmatrix} out \leftarrow 0.000006 \cdot MidSegVolPerLane^2 - 0.0003 \cdot MidSegVolPerLane + 0.0597 \ \ \text{if} \ \ NumSegThruLanes = 1 \\ out \leftarrow 0.016 \exp(0.0055 \cdot MidSegVolPerLane) \ \ \text{if} \ \ NumSegThruLanes \geq 2 \end{vmatrix}$$

$$TurningDelay := \begin{vmatrix} out \leftarrow 0.15 \ \ \text{if} \ \ NumSegThruLanes \geq 3 \wedge MidSegVolPerLane \geq 400 \\ out \leftarrow TurningDelay \ \ \text{otherwise} \end{vmatrix}$$

0.15 is upper limit for 3 or more lanes and flow rate per lane >= 400

$$TurningDelay := TurningDelay \cdot \frac{MidBlockPctTurns}{10}$$

HCM 2010 Exhibit 17-12 assumes 10% left and 10% right turns at the access point. Values are adjusted proportionationally for different turning percentages.

$TurningDelay = 0.12$ sec/veh/access pt

$$TotalTurningDelay := TurningDelay \cdot (NumAccessPtsSubDir + NumAccessPtsOppDir)$$

$TotalTurningDelay = 0.909$ s/veh

$SpeedConstant := 25.6 + 0.47 \cdot PostSpd \qquad SpeedConstant = 46.75$

$CrossSectAdjFact := 1.5 \cdot PropSegRestrictMed - 0.47 \cdot PropSegWithCurb - 3.7 \cdot PropSegRestrictMed \cdot PropSegWithCurb$

$CrossSectAdjFact = -0.47$

$$AccessPtDensity := 5280 \cdot \frac{(NumAccessPtsSubDir + NumAccessPtsOppDir)}{(LinkLength)} \qquad AccessPtDensity = 16.0$$

$$AccessPtAdj := -0.078 \cdot \frac{AccessPtDensity}{NumSegThruLanes} \qquad AccessPtAdj = -0.416$$

$BaseFreeFlowSpd := SpeedConstant + CrossSectAdjFact + AccessPtAdj \qquad BaseFreeFlowSpd = 45.86$

$$SignalSpacingAdjFact := 1.02 - 4.7 \cdot \frac{(BaseFreeFlowSpd - 19.5)}{\max(SegLength, 400)}$$

$$SignalSpacingAdjFact := \left| \begin{array}{l} out \leftarrow SignalSpacingAdjFact \quad \text{if } \; SignalSpacingAdjFact \le 1.0 \\ out \leftarrow 1.0 \quad \text{otherwise} \end{array} \right.$$

$SignalSpacingAdjFact = 0.972$

$FreeFlowSpd := BaseFreeFlowSpd \cdot SignalSpacingAdjFact \qquad FreeFlowSpd = 44.56$

$$ProximityAdjFact := \frac{2}{1 + \left[1 - \frac{MidSegDemand}{(52.8 \cdot NumSegThruLanes \cdot FreeFlowSpd)}\right]^{0.21}} \qquad ProximityAdjFact = 1.043$$

$$RunningTime := \frac{6 - StartUpLostTime}{0.0025 \cdot (SegLength)} + \frac{3600 \cdot (SegLength)}{5280 \cdot FreeFlowSpd} \cdot ProximityAdjFact + TotalTurningDelay + OtherDelay$$

$RunningTime = 45.39$ sec

$$AvgTravelSpd := \frac{3600}{5280} \cdot \frac{SegLength}{RunningTime + ControlDelay} \qquad AvgTravelSpd = 27.06 \text{ mi/h}$$

Appendix E

Two-Lane Highway Facility Example Calculation

Inputs and Initial Computations.

1. Input Roadway and Traffic Data.

Roadway Data

$AnalysisType := 0$ 0 = segment, 1 = facility $\%NPZ := 50$

$Median := 0$ 0 = no median, 1 = median $PostedSpeed := 55$

$Terrain := 1$ Level = 1, Rolling = 2 $FFS := PostedSpeed + 5$

Peak Direction is EB

$L_{up} := 3$ mi $L_{down} := 4$ mi

$L_T := L_{up} + L_{down}$

Traffic Data

$AADT := 10000$ $K := 0.10$ $D := 0.6$ $PHF := 0.95$

$DDHV := AADT \cdot K \cdot D$ $DDHV = 600$ veh / hr

$LocalAdjustmentFactor := 1.0$ $LAF := LocalAdjustmentFactor$

$v_p := \dfrac{DDHV}{PHF \cdot LAF}$ $v_p = 631.6$ $v_o := \dfrac{AADT \cdot K \cdot (1 - D)}{PHF \cdot LAF}$ $v_o = 421.1$

$\%TruckBus := 3$ $\%RV := 2$ $P_T := \dfrac{\%TruckBus + \%RV}{100}$ $P_T = 0.05$

$\%HV_{EB} := 5$ $\%HV_{WB} := 5$ $\%HV_{NB} := 5$ $\%HV_{SB} := 5$

$v_{LT} := 50$ $v_{RT} := 50$ $\%LT := \dfrac{\frac{v_{LT}}{PHF}}{v_p} \cdot 100$ $\%LT = 8.333$

Signal Data

$GreenTime_{EW} := 54$ $GreenTime_{NS} := 26$ $YellowRedTime := 5$

$C := 90$ $g\_C := \dfrac{GreenTime_{EW}}{C}$ $g\_C = 0.6$

$LeftTurnLane := 1$ 0 = No, 1 = Yes

$BaseCapacity := 1700$

2. Determine segment lengths

Length of basic two-lane segment upstream of signal (L1)

$$L_{eff\_up} := 43.2463 + 4.2688\cdot\left(\frac{v_p}{100}\right)^2 + 5.2178\cdot C - 57.3041\cdot\left(\frac{v_p}{100}\right)\cdot\frac{\%LT}{100} - 5.244\cdot C\cdot g\_C$$

$L_{eff\_up} = 369.791$ (ft) $\qquad L_{eff\_up} := \dfrac{L_{eff\_up}}{5280} \qquad L_{eff\_up} = 0.07$ (mi)

$L_1 := L_{up} - L_{eff\_up} \qquad L_1 = 2.930$ (mi)

Length of signalized intersection influence area (L2)

$L_A := \dfrac{0.1655\cdot FFS^{2.0917}}{5280} \qquad L_A = 0.164$ (mi) $\qquad$ Acceleration distance from stop at signal

$L_2 := L_{eff\_up} + L_A \qquad L_2 = 0.234$ (mi)

Length of transition two-lane highway downstream of signalized intersection influence area (L3)

$L_{eff\_down} := 2.218584 - 0.122942\cdot\left(\dfrac{v_p}{100}\right) \qquad L_{eff\_down} = 1.442$ (mi)

$L_3 := L_{eff\_down} - L_A \qquad L_3 = 1.278$ (mi)

Length of basic two-lane segment downstream of signal (L1)

$L_4 := L_T - (L_1 + L_2 + L_3) \qquad L_4 = 2.558$ (mi)

3. Estimate the free-flow speed

$FFS := PostedSpeed + 5 \qquad FFS = 60$ mi/h

4. Calculate the average travel speed on the unaffected upstream segment

$ATS_1 := 49.63$ mi/h $\qquad$ See ATS calculations section below

5. Calculate control delay at the signalized intersection influence area

$ControlDelay := 12.62$ sec/veh $\qquad$ See signal delay calculations section below

6. Determine average travel speed on the unaffected downstream segment

$ATS_4 := 49.63$ mi/h

7. Determine average travel speed on the affected downstream segment

F = user defined Flow   a = maximum Flow   b = minimum Flow
x = maximum Value   y = minimum Value

$$\text{InterpolateFlow}(F,a,x,b,y) := \left|\begin{array}{l} \text{out} \leftarrow y + \dfrac{x-y}{a-b}\cdot(F-b) \\ \text{out} \end{array}\right.$$

$f_{ATS} := \text{InterpolateFlow}(600, 660, 1.800, 440, 1.320)$ $f_{ATS} = 1.669$

$ATS_3 := ATS_4 - f_{ATS}$ $ATS_3 = 47.96$ mi/h

8. Determine the delay of every segment

$L_1 = 2.93$ $S_1 := ATS_1$ $S_1 = 49.63$ $FFS = 60$

$D_1 := \left(\dfrac{L_1}{S_1} - \dfrac{L_1}{FFS}\right)\cdot 3600$ $D_1 = 36.732$

$L_2 = 0.234$

$D_2 := \text{ControlDelay}$ $D_2 = 12.62$

$L_3 = 1.278$ $S_3 := ATS_3$ $S_3 = 47.961$ $FFS = 60$

$D_3 := \left(\dfrac{L_3}{S_3} - \dfrac{L_3}{FFS}\right)\cdot 3600$ $D_3 = 19.246$

$L_4 = 2.558$ $S_4 := ATS_4$ $S_4 = 49.63$ $FFS = 60$

$D_4 := \left(\dfrac{L_4}{S_4} - \dfrac{L_4}{FFS}\right)\cdot 3600$ $D_4 = 32.068$

9. Determine the percent time-delayed of the entire facility

1. The total length of the facility:

$L_t := L_1 + L_2 + L_3 + L_4$ $\qquad L_t = 7$ $\qquad$ mi

2. The total delay of the facility:

$D_T := D_1 + D_2 + D_3 + D_4$ $\qquad D_T = 100.666$ $\qquad$ sec/veh

3. Calculate the total travel time of the facility based on the free flow speed:

$T_{tFFS} := \left(\frac{L_t}{FFS}\right) \cdot 3600$ $\qquad T_{tFFS} = 420$ $\qquad$ sec/veh

4. Calculate the percent time-delayed of the facility:

$PTD := \left(\frac{D_T}{T_{tFFS}}\right) \cdot 100$ $\qquad PTD = 23.97$ $\qquad$ (%)

10. Determine the Level of Service

$$LOS(PTD) := \left| \begin{array}{l} los \leftarrow \text{"A"} \quad \text{if } PTD \le 7.5 \\ los \leftarrow \text{"B"} \quad \text{if } 7.5 < PTD \le 15 \\ los \leftarrow \text{"C"} \quad \text{if } 15 < PTD \le 25 \\ los \leftarrow \text{"D"} \quad \text{if } 25 < PTD \le 35 \\ los \leftarrow \text{"E"} \quad \text{if } 35 < PTD \le 45 \\ los \leftarrow \text{"F"} \quad \text{if } PTD > 45 \\ los \end{array} \right.$$

$LOS(PTD) = \text{"C"}$

Appendix F

NCHRP 3-75 Freeway Weaving Segment Analysis Procedure

Step 1. Data Inputs

OnRampVol := 300 OffRampVol := 400 SegInputVol := 2836 Int_Density := .6666 int/mi

OnRamp%HV := 3 OffRamp%HV := 4 SegInput%HV := 4.141

L_B := 1500 ft FFS := 65 mi/h PHF := .95 fp := .98

Terrain := 1 1 = Level, 2 = Rolling, 3 = Mountainous

**FREEPLAN finds Int_Density by counting parclos and diamond as 1 interchange each, full as 2, and on and off as 1/2 each and adds them. Then, it divides that total number of interchanges by the total length of the facility.*

Config := 1 1 = one-sided weaving segment, 2 = two-sided weaving segment

NumLanes := 4 Number of lanes in weaving section

C_IFL := 2350 pc/h/ln Capacity of basic freeway segment with same FFS as the weaving segment under equivalent ideal conditions

N_WL := 2 Number of lanes from which weaving maneuvers may be made with one lane change or no lane change. 2 or 3 for one sided and 0 for two sided weaving configuration

LC_RF := 1 Minimum number of lane changes that must be made by a single weaving vehicle from the on-ramp to freeway

LC_FR := 1 Minimum number of lane changes that must be made by a single weaving vehicle from freeway to the off-ramp

LC_RR := 0 Minimum number of lane changes that must be made by one ramp-to-ramp to complete a weaving maneuver

Step 2. Volume Adjustment

A. Heavy Vehicle and Volume Adjustments

Passenger Car Equivalents

$$\text{E\_T(Terrain)} := \left|\begin{array}{lll} \text{out} \leftarrow 1.5 & \text{if} & \text{Terrain} = 1 \\ \text{out} \leftarrow 2.5 & \text{if} & \text{Terrain} = 2 \\ \text{out} \leftarrow 4.5 & \text{if} & \text{Terrain} = 3 \end{array}\right.$$

E_T := E_T(Terrain)

E_T = 1.5

**FREEPLAN assumes trucks make up all of the heavy vehicles. Therefore, RV calculations have been left out.*

$$\text{f\_HV\_FF} := \frac{100}{100 + \text{SegInput\%HV}(\text{E\_T} - 1)}$$

$$\text{f\_HV\_FR} := \frac{100}{100 + \text{OffRamp\%HV}(\text{E\_T} - 1)}$$

$$\text{f\_HV\_RF} := \frac{100}{100 + \text{OnRamp\%HV}(\text{E\_T} - 1)}$$

$$\text{f\_HV\_RR} := \frac{100}{100 + \text{OnRamp\%HV}(\text{E\_T} - 1)}$$

$$\text{SegInputVolAdj} := \frac{\text{SegInputVol}}{\text{PHF}\cdot\text{f\_HV\_FF}\cdot\text{fp}} = 3109.258$$

$$\text{OffRampVolAdj} := \frac{\text{OffRampVol}}{\text{PHF}\cdot\text{f\_HV\_FR}\cdot\text{fp}} = 438.238$$

$$\text{OnRampVolAdj} := \frac{\text{OnRampVol}}{\text{PHF}\cdot\text{f\_HV\_RF}\cdot\text{fp}} = 327.068$$

**Freeplan assumes the Freeway to Ramp Volume will have the same %HV as the Off Ramp and that the Freeway to Freeway Volume will have the same %HV as the Segment Input Volume*

$$\text{f\_HV} := \frac{(\text{f\_HV\_FF} + \text{f\_HV\_FR} + \text{f\_HV\_RF} + \text{f\_HV\_RR})}{4}$$

f_HV = 0.983

B. Volumes for Weaving Segments

$v\_RR := .05 \cdot OnRampVolAdj = 16.4$ veh/h **Freeplan assumes the v_RR is 5% of the total On-Ramp volume.*

$v\_FR := OffRampVolAdj - v\_RR = 421.9$ veh/h

$v\_RF := .95 \cdot OnRampVolAdj = 310.7$ veh/h

$v\_FF := SegInputVolAdj - v\_FR = 2687.4$ veh/h

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 3436.3$ veh/h

C. Weaving Demand Flow Rate

$$WeavingDemand(N\_WL) := \left| \begin{array}{l} out \leftarrow v\_RF + v\_FR \quad \text{if} \quad N\_WL \neq 0 \\ out \leftarrow v\_RR \quad \text{if} \quad N\_WL = 0 \end{array} \right.$$

$WeavingFlowRate := WeavingDemand(N\_WL)$

$\boxed{WeavingFlowRate = 733}$ pc/h

D. Non-Weaving Demand Flow Rate

$$NonWeavingDemand(N\_WL) := \left| \begin{array}{l} out \leftarrow v\_FF + v\_RR \quad \text{if} \quad N\_WL \neq 0 \\ out \leftarrow v\_FF + v\_FR + v\_RF \quad \text{if} \quad N\_WL = 0 \end{array} \right.$$

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$\boxed{NonWeavingFlowRate = 2704}$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$\boxed{TotalFlowRate = 3436}$ pc/h

F. Volume Ratio

$VR := \dfrac{WeavingFlowRate}{TotalFlowRate}$ $\boxed{VR = 0.213}$

Step 3. Determine the Maximum Weaving Length

$$MaximumLength := \left[5728(1 + VR)^{1.6}\right] - 1566 \cdot N\_WL$$

$\boxed{MaximumLength = 4672}$ ft $Ls := L_B \cdot .77 = 1155$

If Maximum Length < Ls, then STOP
Analyze ramp junctions separately

Step 4. Determine the Capacity of Weaving Segment

A. Weaving segment capacity determined by density

$$C\_IWL := C\_IFL - \left[438.2\cdot(1+VR)^{1.6}\right] + (0.0765\cdot Ls) + (119.8\cdot N\_WL)$$

$C\_IWL = 2081$ pc/h/ln C_IWL is the capacity per lane under equivalent ideal conditions

$$Cw1 := C\_IWL\cdot NumLanes\cdot f\_HV\cdot fp$$

$Cw1 = 8016$ veh/h Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

$$C\_IW(N\_WL) := \begin{array}{|l} out \leftarrow \dfrac{2400}{VR} \quad \text{if} \quad N\_WL = 2 \\ out \leftarrow \dfrac{3500}{VR} \quad \text{if} \quad N\_WL = 3 \\ out \leftarrow \dfrac{Cw1}{f\_HV\cdot fp} \quad \text{if} \quad N\_WL = 0 \end{array}$$

For two sided segments, no limiting value on flow rate is proposed and thus capacity based on density only is estimated for the segment. Therefore same capacity value is used here to get the final as capacity determined by density for two sided segments.

$C\_IW := C\_IW(N\_WL)$ $C\_IW = 11257$ pc/h C_IW is the capacity of the weaving segment under ideal conditions

$$Cw2 := C\_IW\cdot f\_HV\cdot fp$$

$Cw2 = 10841$ veh/h Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

$$WeavingCapacity := if(Cw1 > Cw2, Cw2, Cw1)$$

$\boxed{WeavingCapacity = 8016}$ veh/h

D. Volume to Capacity (v/c) Ratio

$$VolumeToCapacity := \frac{TotalFlowRate\cdot f\_HV\cdot fp}{WeavingCapacity}$$

$\boxed{VolumeToCapacity = 0.413}$

If v/c ratio >1 then LOS is F
Terminate

Step 5. Determine Configuration Characteristics

$$LC\_MIN(Config) := \begin{array}{|l} out \leftarrow (LC\_RF\cdot v\_RF) + (LC\_FR\cdot v\_FR) \quad \text{if} \quad Config = 1 \\ out \leftarrow (LC\_RR\cdot v\_RR) \quad \text{if} \quad Config = 2 \end{array}$$

$$LC\_MIN := LC\_MIN(Config)$$

$\boxed{LC\_MIN = 733}$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

$$LC\_W(Ls) := \begin{vmatrix} out \leftarrow LC\_MIN + 0.39 \cdot \left[(Ls - 300)^{0.5} \cdot NumLanes^{2} \cdot (1 + Int\_Density)^{0.8} \right] & \text{if} \quad Ls \geq 300 \\ out \leftarrow LC\_MIN \quad \text{if} \quad Ls < 300 & \end{vmatrix}$$

$LaneChangingWeaving := LC\_W(Ls)$

$\boxed{LaneChangingWeaving = 1007}$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

$$I\_NW := \frac{Ls \cdot Int\_Density \cdot NonWeavingFlowRate}{10000} \qquad I\_NW = 208$$

Non Weaving Vehicle Index

$$LC\_NW1 := (0.206 \cdot NonWeavingFlowRate) + (0.542 \cdot Ls) - (192.6 \cdot NumLanes)$$

$$LC\_NW2 := 2135 + 0.233 \cdot (NonWeavingFlowRate - 2000)$$

$$LC\_NW3 := LC\_NW1 + (LC\_NW2 - LC\_NW1) \cdot \frac{(I\_NW - 1300)}{650}$$

$$LC\_NW(I\_NW) := \begin{vmatrix} out \leftarrow LC\_NW1 & \text{if} & I\_NW < 1300 \\ out \leftarrow LC\_NW2 & \text{if} & I\_NW \geq 1950 \\ out \leftarrow LC\_NW3 & \text{if} & 1300 < I\_NW < 1950 \\ out \leftarrow LC\_NW2 & \text{if} & LC\_NW1 \geq LC\_NW2 \end{vmatrix}$$

$LaneChangingNonWeaving := LC\_NW(I\_NW)$

$\boxed{LaneChangingNonWeaving = 413}$ lc/h

C. Total Lane-Changing Rate

$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$

$\boxed{TotalLaneChanging = 1420}$ lc/h

Step 7. Determine Average Speed of Weaving and Non-Weaving Vehicles

A. Average Speed of Weaving Vehicles

$$WeavingIntensityFactor := 0.226 \left(\frac{TotalLaneChanging}{Ls} \right)^{0.789}$$

$WeavingIntensityFactor = 0.266$

$$AverageWeavingSpeed := 15 + \left(\frac{FFS - 15}{1 + WeavingIntensityFactor} \right)$$

$\boxed{AverageWeavingSpeed = 54.5}$ mi/h

B. Average Speed of Non-Weaving Vehicles

$$AverageNonWeavingSpeed := FFS - (0.0072 \cdot LC\_MIN) - \left(0.0048 \cdot \frac{TotalFlowRate}{NumLanes}\right)$$

$\boxed{AverageNonWeavingSpeed = 55.6}$ mi/h

C. Average Speed of All Vehicles

$$AverageSpeed := \frac{WeavingFlowRate + NonWeavingFlowRate}{\left(\frac{WeavingFlowRate}{AverageWeavingSpeed}\right) + \left(\frac{NonWeavingFlowRate}{AverageNonWeavingSpeed}\right)}$$

$\boxed{AverageSpeed = 55.36}$ mi/h

Step 8. Determine the Level of Service

$$Density := \frac{\left(\frac{TotalFlowRate}{NumLanes}\right)}{AverageSpeed}$$

$\boxed{Density = 15.5}$ pc/mi/ln

$$LOS(Density) := \left| \begin{array}{lll} out \leftarrow \text{"A"} & \text{if} & 0 \le Density \le 10 \\ out \leftarrow \text{"B"} & \text{if} & 10 < Density \le 20 \\ out \leftarrow \text{"C"} & \text{if} & 20 < Density \le 28 \\ out \leftarrow \text{"D"} & \text{if} & 28 < Density \le 35 \\ out \leftarrow \text{"E"} & \text{if} & 35 < Density \\ out \leftarrow \text{"F"} & \text{if} & VolumeToCapacity > 1 \end{array} \right.$$

$\boxed{LOS(Density) = \text{"B"}}$