FINAL REPORT

to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
SYSTEMS PLANNING OFFICE

on Project

"LOSPLAN 2012: Updates for the HCM 2010"

FDOT Contract BDK77 977-19, (UF Project 00094779)

September 2012

University of Florida
Transportation Research Center
Department of Civil and Coastal Engineering

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)

Technical Report Documentation Page

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16. Abstract

LOSPLAN is a suite of three software programs (ARTPLAN, FREEPLAN, HIGHPLAN) for calculating performance measures and level of service on arterial streets, freeways, and highways. The software is intended for planning and preliminary engineering applications. It generally implements the analysis methodologies of the Highway Capacity Manual (HCM), but with a number of enhancements based on FDOT-sponsored research and other revisions to better accommodate Florida-specific traffic, roadway, and signal control conditions. This project addressed several aspects of the LOSPLAN software, primarily with respect to updating the calculation methodologies in response to revisions in the methodological calculations in the HCM 2010.

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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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 relate to the equals sign. You will notice two different notations for the equals sign 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 to obtain the numeric results of an expression. 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 (as might be accomplished with the following statements: "y := 10" and "z := 15"), then the expression "x =" would yield 25. Another example would be as follows: "s := 1800/3600", and then typing "s =" would display "s = 0.5". That is, 's' was assigned the value of 1800 divided by 3600 (using :=), which equals 0.5 (as displayed by using =).

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

LOSPLAN 2012: Updates for the HCM 2010

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Introduction

LOSPLAN is a suite of three software programs (ARTPLAN, FREEPLAN, HIGHPLAN) for calculating performance measures and level of service on arterial streets, freeways, and highways. The software is intended for planning and preliminary engineering applications. It generally implements the analysis methodologies of the Highway Capacity Manual (HCM), but with a number of enhancements based on FDOT-sponsored research and other revisions to better accommodate Florida-specific traffic, roadway, and signal control conditions.

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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 provides a general summary of the major computational and user interface revisions made to each of the LOSPLAN programs. Detailed computation documentation for each of the LOSPLAN programs is provided in the appendices.

ARTPLAN

The computational elements of ARTPLAN and its user interface components were revised as necessary to accommodate the HCM 2010 analysis methodology revisions. Specific areas addressed include:

- Signal delay calculation, signal coordination/progression
  Implemented HCM 2010 delay calculation procedure for the through movement. This included revisions to the uniform delay (d1) calculation to directly account for progression (which is a function of arrival type) and a revision to the k-factor (a variable corresponding to signal control method and part of the d2 calculation) calculation.

- Accommodation of permitted left turn phasing
  Per meeting with project manager on 10/12/11, a 'protected+permitted' left turn phasing option has been implemented. Correspondingly, the calculation for queue storage ratio was revised to increase the left turn capacity by 2.5 veh/phase.

- Arterial running speed
  The results of the FDOT arterial classification project (BDK77 931-02) were implemented. More specifically, the proposed method for classifying arterials and determining LOS is now as follows:

- Arterials with a posted speed of 40 mi/h or greater are considered Class 1 arterials. Arterials with a posted speed of 35 mi/h or less are considered Class 2 arterials.
- The service measure used for Level of Service (LOS) is average travel speed, and the LOS threshold speeds are as shown in the following table.

	LOS	FDOT Class 1	FDOT Class 2
HCM 2010 ATS (mph)	A	40	28
	B	31	22
	C	23	16
	D	18	13
	E	15	10

- Setting free-flow speed equal to posted speed plus 5 mi/h has been retained from ARTPLAN 2009, rather than the new free-flow speed calculation from the HCM 2010.

- Multimodal
  The bicycle and pedestrian LOS methodologies are now largely consistent with the HCM 2010. A bicycle sidepath analysis methodology has been added. The transit LOS methodology is still largely consistent with the ARTPLAN 2009 transit LOS methodology, but with the following revisions.
  - Minor revisions to the pedestrian crossing difficulty calculation
  - An adjustment for the relative speed of buses to automobiles was added
  - Removed the 'obstacle to bus stop' input
  - Removed the 'span of service' input
  - Added a 'passenger load factor' input
  - Added an 'amenities' input
  - Added a 'bus stop type' input

- Other
  An 'on-street parking' input and complementary 'parking activity' input was added
  - These inputs affect the 'other delay' value for automobile segment running speed and the pedestrian and bicycle LOS calculations

  The term 'segment' used in previous versions of ARTPLAN has now been changed to 'link'. The combination of link length (distance between intersections) and intersection width yields the segment length.

HIGHPLAN

The computational elements of HIGHPLAN and its user interface components were revised as necessary to accommodate the HCM 2010 analysis methodology revisions. Specific areas addressed include:

- Grade adjustment factor values
  These values were revised to be consistent with the HCM 2010.

- Passenger car equivalency factor values
  These values were revised to be consistent with the HCM 2010.

- Capacity adjustments
  The capacity value for two-lane undeveloped situations was changed from 1600 pc/h/ln to 1650 pc/h/ln. All of the capacity values used in HIGHPLAN 2012 are shown in the following table.

	HIGHPLAN 2012
Two-Lane Undeveloped	1500
Two-Lane Developed	1650
Multilane Undeveloped	1600
Multilane Developed	1850

- Implement two-lane highway facility analysis methodology
  The two-lane highway facility methodology, as originally developed in FDOT project BC 345-89 and then further revised as documented in reference[1], was implemented.

- User interface
  - Changed 'Left Turn Impact' label to 'Left Turn/Blockage Impact'

FREEPLAN

The computational elements of FREEPLAN and its user interface components were revised as necessary to accommodate the HCM 2010 analysis methodology revisions. Specific areas addressed include:

- Full implementation of downstream segment speed constraint
  Due to the segmentation scheme used in previous versions of FREEPLAN (i.e., the use of 'interchange' segment types), there were limitations on the application of eq. 25-2 (HCM 2010). To facilitate completion of this task, the segmentation method for a freeway facility was revised to be completely consistent with that of the HCM Freeway Facilities methodology. The previous segments "full cloverleaf", "partial cloverleaf", and "diamond" have been removed. The segment types present in FREEPLAN 2012 include 'Basic', 'Off-Ramp', 'On-Ramp', 'Overlap', 'Weaving', and 'Toll Plaza'.

- Auxiliary lane service volume adjustments
  Auxiliary lane adjustments are handled completely within the weaving segment analysis

[1] Two-Lane Highway Simulation and Analysis. Ph.D. Dissertation by Jing Li. Faculty Advisor: Dr. Scott Washburn. University of Florida, July 2012.

methodology (per the HCM 2010). Per FDOT project BDK75 977-08, it was found that for segments too long for the weaving analysis to be applicable, in which case the segment is analyzed as a 'basic segment', an auxiliary lane provides very nearly a full lane of capacity (98-99%). Thus, no capacity reduction is made for the auxiliary lane, which is consistent with the HCM 2010 methodology.

- Implement rural LOS thresholds
  The density thresholds for LOS on rural freeways, determined from FDOT project BC 354-92, were implemented.

- Implement toll plaza analysis
  A new toll plaza analysis methodology has been incorporated into the FREEPLAN analysis methodology. The details of this methodology are documented in reference[2].

- User interface
  - The 'Hot Spots' column on the 'Results' screen and the corresponding dialog form were removed, as these were no longer necessary due to the changes in the segmentation scheme.

ALL PROGRAMS

- Treatment of K and peak hour factors
  The PHF default was set to 1.0 for all area type conditions. The default K-factor values were revised to the values given in Table 1 of Mr. McLeod's issue paper on adopting standard K values[3]. The 'K100' terminology previously used in the program was changed to 'Standard K'. A warning message was implemented for the situation when the user changes the K-factor value to something other than the standard value.

- User interface
  - Revised the input segmentation scheme to be fully consistent with the HCM Freeway Facilities methodology.
  - Changed K and D inputs to percentages instead of decimals
  - Disable K factor input if 'Standard K' is chosen
  - Added a warning message when user changes to 'Kother' study period on project properties screen ("By selecting the Kother study period, FDOT may require justification for its use.")
  - The selected study period shown in the printed report is now bolded.
  - A new mechanism for quickly loading previously used files has been implemented.

[2] Implementing Toll Plaza Analysis into FREEPLAN. Master's Thesis by Robin Osborne. Faculty Advisor: Dr. Scott Washburn. University of Florida, April 2012.

[3] DRAFT Issue Paper on Improving Florida's Transportation Planning and Design Analysis Time Period Process (Adopting Standard K Factors throughout FDOT), 5/4/11.

- The printing dialog has been revised to more easily facilitate printing to the non-default printer (such as PDF)

- Updates to LOSPLAN Installation and Beta Testing
  The LOSPLAN installation routine was revised as necessary.

- Updates to the computational methodologies documentation
  The Mathcad worksheets that document the details of the ARTPLAN, HIGHPLAN, and FREEPLAN internal calculations were updated, and are included in the appendices of this report. Note that only one instance of each of the individual segment calculation methodologies for freeway facilities is included in this document (i.e., basic, on-ramp, off-ramp, ramp overlap, and weaving segment methodologies). These represent individual segments from the FREEPLAN example facility, which includes a total of 33 segments. The overall facility calculations, which aggregates the results across all 33 segments is also included. The complete computational documentation for FREEPLAN, as well as HIGHPLAN and ARTPLAN, can be found at the following website: http://www.losplan.net

  This website also contains the ARTPLAN, HIGHPLAN, and FREEPLAN input files that correspond to the computations documentation.

- Updates to the electronic help files
  The electronic help files were updated as necessary.

Appendix A
Automobile Calculations Documentation for ARTPLAN

ARTPLAN Computational Methodology

Automobile Mode

For Version 9/11/2012

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Inputs

Project Properties

Roadway Variables:

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

$Class := 2$

Intersection

Facility-Wide Values:

$BaseSatFlowRate := 1950$ $Sig := 2$ 0 = Pretimed, 1 = Coordinated Actuated, 2 = Fully Actuated

Intersection Data:

Int_1	Int_2	Int_3	Int_4
No Inputs Required	$Cycle_1 := 120$	$Cycle_2 := 150$	$Cycle_3 := 150$
	$gC_1 := 0.50$	$gC_2 := 0.40$	$gC_3 := 0.45$
	$ArrivalType_1 := 4$	$ArrivalType_2 := 3$	$ArrivalType_3 := 5$
	$IntThruLanes_1 := 3$	$IntThruLanes_2 := 3$	$IntThruLanes_3 := 4$
	$\%LeftTurns_1 := 12$	$\%LeftTurns_2 := 7$	$\%LeftTurns_3 := 9$
	$\%RightTurns_1 := 8$	$\%RightTurns_2 := 5$	$\%RightTurns_3 := 4$
	$LeftTurnBay_1 := 1$	$LeftTurnBay_2 := 1$	$LeftTurnBay_3 := 1$
	$RightTurnBay_1 := 0$	$RightTurnBay_2 := 0$	$RightTurnBay_3 := 1$

*For left turn and right turn bays: 0 = No, 1 = Yes

Link (Auto)

Facility-Wide Values:

$K := 0.095$ $D := 0.55$ $PHF := 0.95$ $\%HV := 2.5$

Link Data:

$Link_1$

$LinkLength_1 := 2500$

$AADT_1 := 43250$

$HourlyDirVol_1 := round\left(AADT_1 \cdot K \cdot D\right)$

$HourlyDirVol_1 = 2260$

$LinkNumLanes_1 := 3$

$FFS_1 := 50$

$MedianType_1 := 1$

$OnStreetParking_1 := 1$

$ParkingActivity_1 := 2$

$Link_2$

$LinkLength_2 := 1500$

$AADT_2 := 43250$

$HourlyDirVol_2 := round\left(AADT_2 \cdot K \cdot D\right)$

$HourlyDirVol_2 = 2260$

$LinkNumLanes_2 := 3$

$FFS_2 := 50$

$MedianType_2 := 2$

$OnStreetParking_2 := 0$

$ParkingActivity_2 := 0$

$Link_3$

$LinkLength_3 := 1700$

$AADT_3 := 43250$

$HourlyDirVol_3 := round\left(AADT_3 \cdot K \cdot D\right)$

$HourlyDirVol_3 = 2260$

$LinkNumLanes_3 := 4$

$FFS_3 := 50$

$MedianType_3 := 1$

$OnStreetParking_3 := 0$

$ParkingActivity_3 := 0$

*For MedianType: 0 = None, 1 = NonRestrictive, 2 = Restrictive

*For On-Street Parking: 0 = No, 1 = Yes

*For Parking Activity: 0 = Not Applicable, 1 = Low, 2 = Medium, 3 = High

Auto LOS Computational Steps

1. Calculate the Saturation Flow Rate Adjustment Factors

A. Calculate the population adjustment factor

$$Population(AreaType) := \begin{array}{|l} out \leftarrow 1.5 \ \text{ if } \ AreaType = 1 \\ out \leftarrow 0.4 \ \text{ if } \ AreaType = 2 \\ out \leftarrow 0.03 \ \text{ if } \ AreaType = 3 \\ out \leftarrow 0.003 \ \text{ if } \ AreaType = 4 \end{array}$$

$Population(AreaType) = 1.5$

$$PopFact := \frac{1}{Population(AreaType)^{-0.018}}$$

$PopFact = 1.007$

B. Calculate the number of lanes adjustment factor

$$E_{CL} := 1.03 \qquad NumLnsFact(i) := \frac{1}{1 + \frac{1}{IntThruLanes_i} \cdot (E_{CL} - 1)}$$

$NumLnsFact(1) = 0.99$
$NumLnsFact(2) = 0.99$
$NumLnsFact(3) = 0.993$

C. Calculate the posted speed adjustment factor

* FFS - 5 is equivalent to the posted speed entered in ARTPLAN

$$PostedSpd(i) := \min(\max(30, FFS_i - 5), 55) \qquad SpdFact(i) := \frac{1}{1 - 0.0066(PostedSpd(i) - 50)}$$

$SpdFact(1) = 0.968 \qquad SpdFact(2) = 0.968 \qquad SpdFact(3) = 0.968$

D. Calculate the traffic pressure adjustment factor

$$CalcPctTurns(\%LT, \%RT, i) := \begin{cases} \%LT & \text{if } LeftTurnBay_i = 1 \wedge RightTurnBay_i = 0 \\ \%RT & \text{if } LeftTurnBay_i = 0 \wedge RightTurnBay_i = 1 \\ \%LT + \%RT & \text{if } LeftTurnBay_i = 1 \wedge RightTurnBay_i = 1 \\ 0 & \text{otherwise} \end{cases}$$

$\%Turns_1 := CalcPctTurns(\%LeftTurns_1, \%RightTurns_1, 1) \qquad \%Turns_1 = 12$
$\%Turns_2 := CalcPctTurns(\%LeftTurns_2, \%RightTurns_2, 2) \qquad \%Turns_2 = 7$
$\%Turns_3 := CalcPctTurns(\%LeftTurns_3, \%RightTurns_3, 3) \qquad \%Turns_3 = 13$

$$ThruMvmtFlowRate(i) := \frac{HourlyDirVol_i}{PHF} \cdot \left[1 - \left(\frac{\%Turns_i}{100}\right)\right]$$

$ThruMvmtFlowRate(1) = 2093.5$
$ThruMvmtFlowRate(2) = 2212.4$
$ThruMvmtFlowRate(3) = 2069.7$

$$v(i) := \min\left(\frac{ThruMvmtFlowRate(i) \cdot Cycle_i}{IntThruLanes_i \cdot 3600}, 30\right)$$

$v(1) = 23.261 \qquad v(2) = 30 \qquad v(3) = 21.559$

$$TrafFact(i) := \frac{1}{1 - 0.0032(v(i) - 20)}$$

$TrafFact(1) = 1.011 \qquad TrafFact(2) = 1.033 \qquad TrafFact(3) = 1.005$

E. Calculate the lane width adjustment factor

$$W_{inln}(i) := \begin{cases} 12 & \text{if } W_{outln_i} \geq 12 \\ W_{outln_i} & \text{if } W_{outln_i} < 12 \end{cases}$$

$W_{inln}(1) = 12$
$W_{inln}(2) = 12$
$W_{inln}(3) = 12$

$$W_{avg}(i) := \frac{\left[W_{inln}(i)\cdot\left(IntThruLanes_i - 1\right)\right] + W_{outln_i}}{IntThruLanes_i}$$

$W_{avg}(1) = 12$
$W_{avg}(2) = 12$
$W_{avg}(3) = 12$

$$LnWidthFact(i) := 1 + \frac{W_{avg}(i) - 12}{30}$$

$LnWidthFact(1) = 1.00$
$LnWidthFact(2) = 1.00$
$LnWidthFact(3) = 1.00$

F. Determine the Median adjustment factor

$$MedianFact(i) := \left| \begin{array}{l} out \leftarrow 0.95 \text{ if } MedianType_i = 0 \\ out \leftarrow 1.0 \text{ if } MedianType_i = 1 \\ out \leftarrow 1.0 \text{ if } MedianType_i = 2 \\ out \end{array} \right.$$

$MedianFact(1) = 1.0$
$MedianFact(2) = 1.0$
$MedianFact(3) = 1.0$

G. Determine the left turn bay adjustment factor

$$LTFact(i) := \left| \begin{array}{l} out \leftarrow 0.8 \text{ if } LeftTurnBay_i = 0 \wedge \%LeftTurns_i \neq 0 \\ out \leftarrow 1.0 \text{ if } LeftTurnBay_i = 1 \vee \%LeftTurns_i = 0 \\ out \end{array} \right.$$

$LTFact(1) = 1.0$
$LTFact(2) = 1.0$
$LTFact(3) = 1.0$

H. Determine the right turn adjustment factor

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

$PctMultiplier(1) = 0.069$

$PctMultiplier(2) = 0.065$

$PctMultiplier(3) = 0.064$

$$RTFact(i) := \begin{cases} out \leftarrow 1 - \left(PctMultiplier(i)\cdot\frac{\%RightTurns_i}{12}\right) & \text{if } RightTurnBay_i = 1 \\ out \leftarrow \frac{1}{1 + \left(\frac{\%RightTurns_i}{100}\cdot 0.07\right)} & \text{otherwise} \end{cases}$$

$RTFact(1) = 0.994$
$RTFact(2) = 0.997$
$RTFact(3) = 0.979$

I. Calculate the heavy vehicle adjustment factor

$E_T := 2.3$ (per "Impact of Trucks on Arterial LOS" FDOT project; BD-545-51)

$$f_{HV} := \frac{1}{1 + \left[\frac{\%HV}{100}\cdot\left(E_T - 1\right)\right]}$$

$f_{HV} = 0.969$

2. Calculate the Adjusted Saturation Flow Rate

$$FactAdj(i) := LnWidthFact(i)\cdot MedianFact(i)\cdot f_{HV}\cdot PopFact\cdot TrafFact(i)\cdot NumLnsFact(i)\cdot SpdFact(i)\cdot LTFact(i)\cdot RTFact(i)$$

$FactAdj(1) = 0.94$
$FactAdj(2) = 0.963$
$FactAdj(3) = 0.922$

$AdjSatFlowRate(i) := BaseSatFlowRate\cdot FactAdj(i)$

$AdjSatFlowRate(1) = 1832.41$
$AdjSatFlowRate(2) = 1877.153$
$AdjSatFlowRate(3) = 1798.053$

ARTPLAN reports (IntThruLanes)(AdjSatFlowRate)

$AdjSatFlowRate(1)\cdot IntThruLanes_1 = 5497$
$AdjSatFlowRate(2)\cdot IntThruLanes_2 = 5631$
$AdjSatFlowRate(3)\cdot IntThruLanes_3 = 7192$

3. Calculate signal delay

A. Calculate volume to capacity ratio (v/c)

$ThruMvmtFlowRate(1) = 2093.474$
$ThruMvmtFlowRate(2) = 2212.421$
$ThruMvmtFlowRate(3) = 2069.684$

$c(i) := AdjSatFlowRate(i)\cdot IntThruLanes_i\cdot gC_i$

$c(1) = 2748.616$
$c(2) = 2252.584$
$c(3) = 3236.496$

$$vc(i) := \frac{ThruMvmtFlowRate(i)}{c(i)}$$

$vc(1) = 0.762$
$vc(2) = 0.982$
$vc(3) = 0.639$

1. Determine Platoon Ratio From Exhibit 18-8 HCM 2010

$$CalcR_p(i) := \begin{array}{|l} out \leftarrow 0.333 \;\; \text{if} \;\; ArrivalType_i = 1 \\ out \leftarrow 0.667 \;\; \text{if} \;\; ArrivalType_i = 2 \\ out \leftarrow 1.0 \;\; \text{if} \;\; ArrivalType_i = 3 \\ out \leftarrow 1.333 \;\; \text{if} \;\; ArrivalType_i = 4 \\ out \leftarrow 1.667 \;\; \text{if} \;\; ArrivalType_i = 5 \\ out \leftarrow 2 \;\; \text{otherwise} \\ out \end{array}$$

$R_{p_1} := CalcR_p(1)$ $\quad R_{p_1} = 1.333$

$R_{p_2} := CalcR_p(2)$ $\quad R_{p_2} = 1$

$R_{p_3} := CalcR_p(3)$ $\quad R_{p_3} = 1.667$

2. Calculate the proporation of arrivals on green Equation 18-2 HCM 2010

$$CalcPropGreen(i) := \begin{array}{|l} out \leftarrow 1.0 \;\; \text{if} \;\; \left(R_{p_i} \cdot gC_i\right) > 1.0 \\ out \leftarrow R_{p_i} \cdot gC_i \;\; \text{otherwise} \\ out \end{array}$$

$PropGreen_1 := CalcPropGreen(1)$ $\quad PropGreen_1 = 0.667$

$PropGreen_2 := CalcPropGreen(2)$ $\quad PropGreen_2 = 0.4$

$PropGreen_3 := CalcPropGreen(3)$ $\quad PropGreen_3 = 0.75$

3. Calculate the flow rates during green and red Eqs. 18-23, 18-24 HCM 2010

$$FlowRateGreen(i) := \frac{\frac{ThruMvmtFlowRate(i)}{3600} \cdot PropGreen_i}{gC_i}$$

$FlowRateGreen(1) = 0.775$ veh/sec

$FlowRateGreen(2) = 0.615$

$FlowRateGreen(3) = 0.958$

$$FlowRateRed(i) := \frac{\frac{ThruMvmtFlowRate(i)}{3600} \cdot \left(1 - PropGreen_i\right)}{\left(1 - gC_i\right)}$$

$FlowRateRed(1) = 0.388$

$FlowRateRed(2) = 0.615$

$FlowRateRed(3) = 0.261$

4. Calculate uniform delay (d_1)

$RedTime(i) := Cycle_i - Cycle_i \cdot gC_i$

$RedTime(1) = 60$

$RedTime(2) = 90$

$RedTime(3) = 82.5$

$$TimeQueueClear(i) := \frac{FlowRateRed(i)\cdot RedTime(i)}{\frac{AdjSatFlowRate(i)\cdot IntThruLanes_i}{3600} - FlowRateGreen(i)}$$

$TimeQueueClear(1) = 30.954$

$TimeQueueClear(2) = 58.238$

$TimeQueueClear(3) = 20.728$

$$TotalDelay(i) := \left(0.5\cdot FlowRateRed(i)\cdot RedTime(i)^2\right) + (0.5\cdot FlowRateRed(i)\cdot RedTime(i)\cdot TimeQueueClear(i))$$

$TotalDelay(1) = 1058.36$

$TotalDelay(2) = 4099.56$

$TotalDelay(3) = 1112.093$

$$d_1(i) := \frac{TotalDelay(i)}{\left(\frac{ThruMvmtFlowRate(i)}{3600}\cdot Cycle_i\right)}$$

$d_1(1) = 15.17$

$d_1(2) = 44.47$

$d_1(3) = 12.90$

5. Calculate incremental delay (d_2)

a. Determine k, signal controller mode delay adjustment factor

If the intersection is operating under pretimed mode, k = 0.5.

$PassTime := 2.0$

$$kmin := max\left(0.04, -0.375 + 0.354\cdot PassTime - 0.0910\cdot PassTime^2 + 0.00889\cdot PassTime^3\right)$$

$kmin = 0.04$

$$kfact(i) := \left| \begin{array}{l} return\ .5\ \ if\ \ Sig = 0 \\ return\ .5\ \ if\ \ Sig = 1 \\ return\ (1 - 2\cdot kmin)\cdot(vc(i) - 0.5) + kmin\ \ if\ \ Sig = 2 \end{array} \right.$$

Eqs. 18-41, 18-42 HCM 2010

$k_1 := kfact(1)$ $k_2 := kfact(2)$ $k_3 := kfact(3)$

$k_1 = 0.281$

$k_2 = 0.484$

$k_3 = 0.168$

Note: k cannot exceed 0.5

b. Determine I, the upstream filtering/metering adjustment factor

If the v/c ratio for the upstream signal is greater than 1, then I = 0.09.

When there is no upstream signal, use the v/c ratio for that intersection.

$$\text{Ifact}(i) := \begin{array}{|l} \text{return } 1.0 - 0.91\cdot vc(i)^{2.68} \text{ if } vc(i) < 1 \wedge i = 1 \\ \text{return } 0.09 \text{ if } vc(i) \geq 1 \wedge i = 1 \\ \text{return } 1.0 - 0.91\cdot vc(i-1)^{2.68} \text{ if } vc(i-1) < 1.0 \\ \text{return } 0.09 \text{ if } vc(i-1) \geq 1.0 \end{array}$$

From Exhibit 18-3 HCM 2010

$I_1 := \text{Ifact}(1)$ $I_2 := \text{Ifact}(2)$ $I_3 := \text{Ifact}(3)$

$I_1 = 0.561$
$I_2 = 0.561$
$I_3 = 0.133$

$T := 0.25$ (ARTPLAN default)

Equation 18-45 HCM 2010

$$d_2(i) := 900\cdot T\cdot\left[(vc(i) - 1) + \sqrt{(vc(i) - 1)^2 + \frac{8\cdot k_i\cdot I_i\cdot vc(i)}{T\cdot c(i)}}\right]$$

$d_2(1) = 0.656$
$d_2(2) = 10.405$
$d_2(3) = 0.044$

6. Calculate the total signal delay

Equation 18-19 HCM 2010

$\text{CalcCtrlDelay}(i) := d_1(i) + d_2(i)$

$\text{CtrlDelay}_1 := \text{CalcCtrlDelay}(1)$ $\text{CtrlDelay}_1 = 15.82$
$\text{CtrlDelay}_2 := \text{CalcCtrlDelay}(2)$ $\text{CtrlDelay}_2 = 54.88$
$\text{CtrlDelay}_3 := \text{CalcCtrlDelay}(3)$ $\text{CtrlDelay}_3 = 12.94$

4. Calculate the Segment and Facility Running Time/Speed

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

$\text{IntWidth} = 60$

$\text{SegLength}(i) := \text{LinkLength}_i + \text{IntWidth}$

$\text{SegLength}(1) = 2560$ ft
$\text{SegLength}(2) = 1560$
$\text{SegLength}(3) = 1760$

A. Calculate the signal density

$$\text{CalcSigs}(i) := \min\left(\frac{5280}{\text{SegLength}(i)}, 9\right)$$

$\text{SigsPerMile}_1 := \text{CalcSigs}(1)$ $\text{SigsPerMile}_1 = 2.063$
$\text{SigsPerMile}_2 := \text{CalcSigs}(2)$ $\text{SigsPerMile}_2 = 3.385$
$\text{SigsPerMile}_3 := \text{CalcSigs}(3)$ $\text{SigsPerMile}_3 = 3.00$

B. Calculate the peak per-lane hourly volume

$$Calcv\_temp(i) := \min\left(\frac{HourlyDirVol_i}{LinkNumLanes_i \cdot PHF}, 1000\right)$$

$v\_temp_1 := Calcv\_temp(1)$ $\quad v\_temp_1 = 792.982$ veh/h

$v\_temp_2 := Calcv\_temp(2)$ $\quad v\_temp_2 = 792.982$ veh/h

$v\_temp_3 := Calcv\_temp(3)$ $\quad v\_temp_3 = 594.737$ veh/h

C. Calculate the running speed

$$MidSegDemand(i) := \frac{HourlyDirVol_i}{PHF}$$

$MidSegDemand(1) = 2378.9$ veh/h

$MidSegDemand(2) = 2378.9$

$MidSegDemand(3) = 2378.9$

$$MidBlockPctTurns := \begin{array}{|l} out \leftarrow 7 \text{ if } AreaType = 1 \\ out \leftarrow 5 \text{ if } AreaType = 2 \\ out \leftarrow 3 \text{ if } AreaType = 3 \\ out \leftarrow 2 \text{ if } AreaType = 4 \end{array}$$

$MidBlockPctTurns = 7$

$$PropSegRestrictMed(i) := \begin{array}{|l} out \leftarrow 0 \text{ if } MedianType_i = 0 \\ out \leftarrow 0 \text{ if } MedianType_i = 1 \\ out \leftarrow 1.0 \text{ if } MedianType_i = 2 \end{array}$$

Proportion of segment length with restricted median

$PropSegRestrictMed(1) = 0$

$PropSegRestrictMed(2) = 1$

$PropSegRestrictMed(3) = 0$

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

Proportion of segment length with right-side curb

$PropSegWithCurb = 1.0$

$$NumAccessPts(i) := \begin{array}{|l} out \leftarrow 0 \text{ if } LinkLength_i < 660 \\ out \leftarrow 2 \cdot \frac{LinkLength_i}{1320} \text{ if } LinkLength_i \geq 660 \end{array}$$

$NumAccessPts(1) = 3.79$

$NumAccessPts(2) = 2.27$

$NumAccessPts(3) = 2.58$

$$NumAccessPtsSubDir(i) := NumAccessPts(i)$$

Number of access points in the subject direction

$NumAccessPtsSubDir(1) = 3.79$

$NumAccessPtsSubDir(2) = 2.27$

$NumAccessPtsSubDir(3) = 2.58$

$NumAccessPtsOppDir(i) := NumAccessPts(i)$

For planning purposes, assume opposing direction has same number of access points as subject direction

$NumAccessPtsOppDir(1) = 3.79$

$NumAccessPtsOppDir(2) = 2.27$

$NumAccessPtsOppDir(3) = 2.58$

$$OtherDelay(i) := \begin{cases} \text{return } 0 \text{ if } OnStreetParking_i = 0 \\ \text{if } OnStreetParking_i = 1 \\ \quad \text{return } \dfrac{2}{LinkNumLanes_i} \text{ if } ParkingActivity_i = 1 \\ \quad \text{return } \dfrac{4}{LinkNumLanes_i} \text{ if } ParkingActivity_i = 2 \\ \quad \text{return } \dfrac{6}{LinkNumLanes_i} \text{ if } ParkingActivity_i = 3 \end{cases}$$

planning level assumptions

$OtherDelay(1) = 1.33$ sec/veh

$OtherDelay(2) = 0.00$

$OtherDelay(3) = 0.00$

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

$ControlDelay := 16.1$ Obtained from signal delay calculation procedure

$$MidSegVolPerLane(i) := \frac{MidSegDemand(i)}{LinkNumLanes_i}$$

$MidSegVolPerLane(1) = 793.0$ veh/h/ln

$MidSegVolPerLane(2) = 793.0$

$MidSegVolPerLane(3) = 594.7$

$$TurningDelay(i) := \begin{cases} out \leftarrow 0.0208 \cdot \exp(0.0022 \cdot MidSegVolPerLane(i)) \text{ if } LinkNumLanes_i = 1 \\ out \leftarrow 0.00014325313\, MidSegVolPerLane(i) \text{ if } LinkNumLanes_i = 2 \\ out \leftarrow 0.000109151\, MidSegVolPerLane(i) \text{ if } LinkNumLanes_i \geq 3 \end{cases}$$

$$TurningDelay(i) := TurningDelay(i) \cdot \frac{MidBlockPctTurns}{7}$$

7% turns is assumed typical condition for Florida. Values are adjusted proportionally for different turning percentages.

$TurningDelay(1) = 0.087$ sec/veh/access pt

$TurningDelay(2) = 0.087$

$TurningDelay(3) = 0.065$

$$\text{TotalTurningDelay}(i) := \text{TurningDelay}(i)\cdot(\text{NumAccessPtsSubDir}(i) + \text{NumAccessPtsOppDir}(i))$$

$\text{TotalTurningDelay}(1) = 0.656$ s/veh

$\text{TotalTurningDelay}(2) = 0.393$

$\text{TotalTurningDelay}(3) = 0.334$

$$\text{PostedSpeed}(i) := \text{FFS}_i - 5$$

$$\text{SpeedConstant}(i) := 25.6 + 0.47\cdot\text{PostedSpeed}(i)$$

$\text{SpeedConstant}(1) = 46.75$ mi/h

$\text{SpeedConstant}(2) = 46.75$

$\text{SpeedConstant}(3) = 46.75$

$$\text{CrossSectAdjFact}(i) := 1.5\cdot\text{PropSegRestrictMed}(i) - 0.47\cdot\text{PropSegWithCurb} - 3.7\cdot\text{PropSegRestrictMed}(i)\cdot\text{PropSegWithCurb}$$

$\text{CrossSectAdjFact}(1) = -0.47$

$\text{CrossSectAdjFact}(2) = -2.67$

$\text{CrossSectAdjFact}(3) = -0.47$

$$\text{AccessPtDensity}(i) := 5280\cdot\frac{(\text{NumAccessPtsSubDir}(i) + \text{NumAccessPtsOppDir}(i))}{\left(\text{LinkLength}_i\right)}$$

$\text{AccessPtDensity}(1) = 16.0$

$\text{AccessPtDensity}(2) = 16.0$

$\text{AccessPtDensity}(3) = 16.0$

$$\text{AccessPtAdj}(i) := -0.078\cdot\frac{\text{AccessPtDensity}(i)}{\text{LinkNumLanes}_i}$$

$\text{AccessPtAdj}(1) = -0.416$

$\text{AccessPtAdj}(2) = -0.416$

$\text{AccessPtAdj}(3) = -0.312$

$$\text{BaseFreeFlowSpd}(i) := \text{SpeedConstant}(i) + \text{CrossSectAdjFact}(i) + \text{AccessPtAdj}(i)$$

$\text{BaseFreeFlowSpd}(1) = 45.86$

$\text{BaseFreeFlowSpd}(2) = 43.66$

$\text{BaseFreeFlowSpd}(3) = 45.97$

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

$$\text{SignalSpacingAdjFact}(i) := \begin{array}{|l} \text{out} \leftarrow \text{SignalSpacingAdjFact}(i) \quad \text{if } \ \text{SignalSpacingAdjFact}(i) \le 1.0 \\ \text{out} \leftarrow 1.0 \quad \text{otherwise} \end{array}$$

$\text{SignalSpacingAdjFact}(1) = 0.972$

$\text{SignalSpacingAdjFact}(2) = 0.947$

$\text{SignalSpacingAdjFact}(3) = 0.949$

$$ProximityAdjFact(i) := \frac{2}{1 + \left[1 - \frac{MidSegDemand(i)}{\left(52.8 \cdot LinkNumLanes_i \cdot FFS_i\right)}\right]^{0.21}}$$

ProximityAdjFact(1) = 1.037

ProximityAdjFact(2) = 1.037

ProximityAdjFact(3) = 1.027

D. Calculate segment running time

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

RunningTime(1) = 38.83 sec

RunningTime(2) = 23.49

RunningTime(3) = 25.89

F. Calculate the segment average speed

$$AvgSegmentSpd(i) := \frac{3600}{5280} \cdot \frac{SegLength(i)}{RunningTime(i) + CtrlDelay_i}$$

AvgSegmentSpd(1) = 31.94 mi/h

AvgSegmentSpd(2) = 13.57

AvgSegmentSpd(3) = 30.91

G. Calculate the facility travel time and speed

$$FacTravTime := \left(\frac{SegLength(1)}{5280\ AvgSegmentSpd(1)}\right) + \left(\frac{SegLength(2)}{5280 \cdot AvgSegmentSpd(2)}\right) + \left(\frac{SegLength(3)}{5280 \cdot AvgSegmentSpd(3)}\right)$$

FacTravTime = 0.048 hours

$$AvgFacilitySpeed := \frac{SegLength(1) + SegLength(2) + SegLength(3)}{5280 \cdot FacTravTime}$$

AvgFacilitySpeed = 23.33 mi/h

5. Determine Segment LOS.

FDOT LOS Methodology, from FDOT Report BDK-77, TWO 931-02

$SegLOS_1 := CalcLOS(Class, AvgSegmentSpd(1))$

$SegLOS_2 := CalcLOS(Class, AvgSegmentSpd(2))$

$SegLOS_3 := CalcLOS(Class, AvgSegmentSpd(3))$

$SegLOS_1 = \text{"A"}$

$SegLOS_2 = \text{"D"}$

$SegLOS_3 = \text{"A"}$

$$
CalcLOS(Class, Speed) := \left|
\begin{array}{l}
\text{if } Class = 1 \\
\quad \left| \begin{array}{l}
out \leftarrow \text{"A"} \quad \text{if } Speed > 40 \\
out \leftarrow \text{"B"} \quad \text{if } 31 < Speed \le 40 \\
out \leftarrow \text{"C"} \quad \text{if } 23 < Speed \le 31 \\
out \leftarrow \text{"D"} \quad \text{if } 18 < Speed \le 23 \\
out \leftarrow \text{"E"} \quad \text{if } 15 < Speed \le 18 \\
out \leftarrow \text{"F"} \quad \text{if } Speed \le 15
\end{array} \right. \\
\text{if } Class = 2 \\
\quad \left| \begin{array}{l}
out \leftarrow \text{"A"} \quad \text{if } Speed > 28 \\
out \leftarrow \text{"B"} \quad \text{if } 22 < Speed \le 28 \\
out \leftarrow \text{"C"} \quad \text{if } 17 < Speed \le 22 \\
out \leftarrow \text{"D"} \quad \text{if } 13 < Speed \le 17 \\
out \leftarrow \text{"E"} \quad \text{if } 10 < Speed \le 13 \\
out \leftarrow \text{"F"} \quad \text{if } Speed \le 10
\end{array} \right. \\
out
\end{array}
\right.
$$

6. Determine Facility LOS.

$FacLOS := CalcLOS(Class, AvgFacilitySpeed)$

$FacLOS = \text{"B"}$

Appendix B
Multimodal Calculations Documentation for ARTPLAN

ARTPLAN 2012 Computational Methodology

Multimodal

For Version 9/11/2012

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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

$PassLoadFact := 0.8$ Passenger loading factor

$Amenities_1 := 4$

1 - Poor (No bench or shelter)
2 - Fair (Bench only)
3 - Good (Shelter only)
4 - Excellent (Shelter & Bench)

$BusStop := 1$ 0 = None 1 = Typical, 2 = Major

Calculated or Assumed Inputs

$HourlyDirVol_1 := round\left(AADT_1 \cdot K \cdot D\right)$ $HourlyDirVol_1 = 2260$ 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

$RunningTime := 38.83$ sec From running time calculation

$$SegAutoRunningSpd := \frac{3600}{5280} \cdot \frac{SegLength_1}{RunningTime} = 45.0$$

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

$SegAutoAvgSpd := 31.9$ Segment auto average speed; does 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

$ControlDelay := 15.8$ From signal delay calculations

$ParkStripes := 1$ 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)

$$CrossStreetLanes := \frac{IntWidth}{12}$$

$CrossStreetLanes = 5$ total lanes in the cross-street (both directions)

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

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

$g_{walk} := gC_1 \cdot \text{Cycle}_1 = 60.0$ sec

$$\text{AvgPedXingWait} := \frac{0.5 \cdot \left(\text{Cycle}_1 - g_{walk}\right)^2}{\text{Cycle}_1} = 15.0$$ sec Equation 18-67, HCM 2010

$$\text{RTORandPermLT} := \text{MajorStreetFlowRate}_1 \cdot \left(1 - \%\text{Green}_1\right) \cdot \frac{\%\text{RightTurns}_1}{100} = 63.4$$ Conflicting movement approximation (veh/h)

$\text{NumRTIslands} := 0$ # 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

$p_{pk} = 0.5$

$$W_{ol} := \begin{array}{|l} \text{return } 10 \text{ if } W_{outln_1} = 0 \\ \text{return } 12 \text{ if } W_{outln_1} = 1 \\ \text{return } 14 \text{ if } W_{outln_1} = 2 \\ \left(\text{return } W_{outln_1}\right) \text{ otherwise} \end{array}$$ Width of outside lane (ft)

$W_{ol} = 12$

$W_{bl} := 5 \cdot \text{ShoulderBikeLn}_1 = 5$ Width of bike lane (ft)

$$W_{os} := \begin{array}{|l} \text{return } 0 \text{ if OnStreetParking} = 0 \\ \text{return } 8 \text{ if OnStreetParking} = 1 \end{array}$$ Width of paved outside shoulder (ft)

$W_{os} = 8$

$$W_A := \begin{array}{|l} \text{out} \leftarrow 6 \cdot \text{Sidewalk}_1 \text{ if SwRdwySep}_1 = 0 \\ \text{out} \leftarrow 10 \cdot \text{Sidewalk}_1 \text{ if SwRdwySep}_1 = 1 \\ \text{out} \leftarrow 15 \cdot \text{Sidewalk}_1 \text{ if SwRdwySep}_1 = 2 \end{array}$$ Available sidewalk width (ft)

$W_{buf} := 2 \cdot \text{Sidewalk}_1 = 2$ Width of sidewalk/roadway buffer (ft)

Pedestrian Intersection

$F_w := 0.681 \cdot \text{CrossStreetLanes}^{0.514}$ $F_w = 1.557$ 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

$PedIntScore := 0.5997 + F_w + F_v + F_s + F_{delay}$ $PedIntScore = 3.05$ Equation 18-68, HCM 2010

Pedestrian Link

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

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

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

$$W_1 := \begin{cases} \text{return } (W_{bl} + W_{os}) & \text{if } p_{pk} < 0.25 \vee ParkStripes = 1 \\ (\text{return } 10) & \text{otherwise} \end{cases}$$ $W_1 = 13.0$ 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

$F_w := -1.2276 \cdot \ln(W_v + 0.5 \cdot W_1 + 50 \cdot p_{pk} + W_{buf} \cdot f_b + W_{aA} \cdot f_{sw})$ $F_w = -5.514$

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

$$F_s := 4\cdot\left(\frac{SegAutoRunningSpd}{100}\right)^2$$ $F_s = 0.808$

$PedLinkScore := 6.0468 + F_w + F_v + F_s$ $PedLinkScore = 3.15$

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

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

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

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

$PedSegScore := 0.318\cdot PedLinkScore + 0.220\cdot PedIntScore + 1.606$ Equation 17-36 HCM 2010

$PedSegScore = 3.28$ Pedestrian perception index

Bicycle Intersection

$W_t := W_{ol} + W_{bl} + OnStreetParking\cdot W_{os}$ $W_t = 25$

$F_w := 0.0153\cdot W_{cd} - 0.2144\cdot W_t$ $F_w = -4.442$

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

$$BikeIntScore := 4.1324 + F_w + F_v \qquad BikeIntScore = 1.00$$

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

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

From Exhibit 17-21, HCM 2010

$W_e = 20$ ft

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

From Exhibit 17-21, 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)]

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

$TF = 0.025$

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

From Exhibit 17-20, HCM 2010

$v_{ma} = 2378.9$ veh/h

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

From Exhibit 17-20, HCM 2010

$S_{Ra} = 44.95$ 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

$P_c = 3.5$

$$F_w := -\left(0.005 \cdot W_e^{\,2}\right) \qquad F_w = -2$$

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

$$F_s := 0.199 \cdot \left(1.1199 \cdot \ln\left(S_{Ra} - 20\right) + 0.8103\right) \cdot \left(1 + 0.1038 \cdot PctHV_a\right)^2 \qquad F_s = 1.393$$

$$F_{s2} := 0.199 \cdot \left(1.1199 \cdot \ln\left(S_{Ra} - 20\right) + 0.8103\right) \cdot (1 + 10.38 \cdot TF)^2 \qquad F_{s2} = 1.393$$

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

$$BikeLinkScore := 0.760 + F_w + F_v + F_{s2} + F_p \qquad BikeLinkScore = 3.41$$

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

$F_{bi} := 1.0$ signalized intersection

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

$BikeSegScore = 3.70$

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

LOS(PedIntScore) = "C" LOS(BikeIntScore) = "A"

LOS(PedLinkScore) = "C" LOS(BikeLinkScore) = "C"

LOS(PedSegScore) = "C" LOS(BikeSegScore) = "D"

Transit Link LOS Computational Steps

$PedLOSGrade_1 :=$ LOS(PedLinkScore) = "C"

1. Determine adjustment factors

A. Calculate pedestrian LOS adjustment

$$PedAdj(i) := \begin{vmatrix} \text{return } 1.15 \text{ if } PedLOSGrade_i = \text{"A"} \\ \text{return } 1.1 \text{ if } PedLOSGrade_i = \text{"B"} \\ \text{return } 1.05 \text{ if } PedLOSGrade_i = \text{"C"} \\ \text{return } 1.0 \text{ if } PedLOSGrade_i = \text{"D"} \\ \text{return } 0.85 \text{ if } PedLOSGrade_i = \text{"E"} \\ \text{return } 0.55 \text{ if } PedLOSGrade_i = \text{"F"} \end{vmatrix}$$

$PedAdj(1) = 1.05$

B. Calculate passenger load factor adjustment

$$LoadFact(i) := \begin{vmatrix} out \leftarrow 1.05 \text{ if } PassLoadFact < 0.3 \\ out \leftarrow 1.0 \text{ if } PassLoadFact < 0.7 \\ out \leftarrow 0.95 \text{ if } PassLoadFact \le 1 \\ out \leftarrow 0.85 \text{ if } PassLoadFact > 1 \end{vmatrix}$$

$LoadFact(1) = 0.95$

C. Calculate roadway crossing difficulty adjustment

$$CrossAdj(i) := \begin{vmatrix} out \leftarrow 0.8 \text{ if } \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 200 \wedge SegNumLanes_1 = 1 \wedge MedianType_1 = 2 \\ out \leftarrow 0.875 \text{ if } \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 350 \wedge SegNumLanes_1 \le 2 \wedge MedianType_1 \le 2 \\ out \leftarrow 0.95 \text{ if } \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 550 \wedge SegNumLanes_1 \le 3 \wedge MedianType_1 \le 1 \\ out \leftarrow 1.0 \text{ if } \frac{MajorStreetFlowRate_1}{SegNumLanes_1} < 775 \wedge SegNumLanes_1 \le 4 \wedge MedianType_1 \le 1 \\ out \leftarrow 1.05 \text{ if } \frac{MajorStreetFlowRate_1}{SegNumLanes_1} \ge 775 \wedge SegNumLanes_1 \le 4 \wedge MedianType_1 \le 1 \end{vmatrix}$$

$CrossAdj(1) = 1.05$

D. Calculate the amenities adjustment

$$AmenitiesAdj(i) := \begin{vmatrix} \text{return } 0.9 \text{ if } Amenities_1 = 1 \\ \text{return } 1.0 \text{ if } Amenities_1 = 2 \\ \text{return } 1.0 \text{ if } Amenities_1 = 3 \\ \text{return } 1.1 \text{ if } Amenities_1 = 4 \end{vmatrix}$$

$AmenitiesAdj(1) = 1.1$

E. Calculate the relative transit speed adjustment

$$S_{Rt} := \min\left(\text{SegAutoRunningSpd}, \frac{49}{1 + \exp\left(-3.54 + \frac{1937}{\text{Length}_1}\right)}\right) = 44.951$$

Equation 17-45 HCM 2010
transit vehicle running speed

$$r_{dt} := 0.540 + 0.0698 \cdot S_{Rt} = 3.678$$

Equation 17-48 HCM 2010
transit vehicle deceleration rate

$$r_{at} := 0.540 + 0.0698 \cdot S_{Rt} = 3.678$$

transit vehicle acceleration rate

$$d_{ad} := \left(\frac{5280}{3600}\right) \cdot \left(\frac{S_{Rt}}{2}\right) \cdot \left(\frac{1}{r_{at}} + \frac{1}{r_{dt}}\right) = 17.927$$

Equation 17-46 HCM 2010
transit vehicle accel/decel delay due to transit stop, minus f_ad term

$$d_{ps} := \begin{vmatrix} \text{out} \leftarrow 0 \ \text{ if BusStop} = 0 \\ \text{out} \leftarrow 15 \ \text{ if BusStop} = 1 \\ \text{out} \leftarrow 35 \ \text{ if BusStop} = 2 \end{vmatrix}$$

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

$$d_{ps} = 15$$

$$d_{re} := 0$$

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

$$d_{ts} := d_{ad} + d_{ps} + d_{re} = 32.927$$

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

$$t_{Rt} := \frac{3600 \cdot \text{Length}_1}{5280 \cdot S_{Rt}} + d_{ts} = 70.847$$

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

$$S_{Ttseg} := \frac{(3600 \cdot \text{Length}_1)}{5280 \cdot (t_{Rt} + \text{ControlDelay})} = 19.672$$

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

$$\text{RelativeBusSpeed}_1 := \frac{S_{Ttseg}}{\text{SegAutoAvgSpd}} = 0.617$$

$$\text{SpeedAdj}(i) := \begin{array}{|l} \text{return } 1.5 \text{ if RelativeBusSpeed}_i \ge 0.90 \\ \text{return } 1.2 \text{ if RelativeBusSpeed}_i \ge 0.75 \\ \text{return } 1.0 \text{ if RelativeBusSpeed}_i \ge 0.60 \\ \text{return } 0.9 \text{ if RelativeBusSpeed}_i \ge 0.50 \\ \text{return } 0.7 \text{ if RelativeBusSpeed}_i < 0.50 \end{array}$$

$\text{SpeedAdj}(1) = 1.0$

2. Determine Link Bus LOS.

$$\text{ModifiedFrequency}(i) := \text{BusFrequency}_i \cdot \text{PedAdj}(i) \cdot \text{LoadFact}(i) \cdot \text{CrossAdj}(i) \cdot \text{AmenitiesAdj}(i) \cdot \text{SpeedAdj}(i)$$

$\text{ModifiedFrequency}(1) = 2.30$

$$\text{BusLOS}(i) := \begin{array}{|l} \text{out} \leftarrow \text{"A" if ModifiedFrequency}(i) > 6 \\ \text{out} \leftarrow \text{"B" if } 4 < \text{ModifiedFrequency}(i) \le 6 \\ \text{out} \leftarrow \text{"C" if } 3 \le \text{ModifiedFrequency}(i) \le 4 \\ \text{out} \leftarrow \text{"D" if } 2 \le \text{ModifiedFrequency}(i) < 3 \\ \text{out} \leftarrow \text{"E" if } 1 \le \text{ModifiedFrequency}(i) < 2 \\ \text{out} \leftarrow \text{"F" if ModifiedFrequency}(i) < 1 \end{array}$$

$\text{BusLOS}(1) = \text{"D"}$

3. Determine Facility Bus LOS.

The values immediately below are from the ARTPLAN output for the example file

$\text{ModifiedFrequency2} := 2.19$ $\text{ModifiedFrequency3} := 1.88$ $\text{Length2} := 1500$ $\text{Length3} := 1700$

$$\text{FacilityAdjBuses} := \frac{\text{ModifiedFrequency}(1) \cdot \text{Length}_1 + \text{ModifiedFrequency2} \cdot \text{Length2} + \text{ModifiedFrequency3} \cdot \text{Length3}}{\text{Length}_1 + \text{Length2} + \text{Length3}}$$

$\text{FacilityAdjBuses} = 2.15$

$$\text{FacilityBusLOS} := \begin{array}{|l} \text{out} \leftarrow \text{"A" if FacilityAdjBuses} > 6 \\ \text{out} \leftarrow \text{"B" if } 4 < \text{FacilityAdjBuses} \le 6 \\ \text{out} \leftarrow \text{"C" if } 3 \le \text{FacilityAdjBuses} \le 4 \\ \text{out} \leftarrow \text{"D" if } 2 \le \text{FacilityAdjBuses} < 3 \\ \text{out} \leftarrow \text{"E" if } 1 \le \text{FacilityAdjBuses} < 2 \\ \text{out} \leftarrow \text{"F" if FacilityAdjBuses} < 1 \end{array}$$

$\text{FacilityBusLOS} = \text{"D"}$

Appendix C
Calculations Documentation for HIGHPLAN (Two-Lane)

HIGHPLAN Computational Methodology

For Version 7/19/2012

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Transportation Research Center

Two-Lane Methodology

Inputs

Project Properties

Roadway Information:

$AreaType := 2$ 1 = Urbanized, 2 = Transitioning/Urban, 3 = Rural developed, 4 = Rural undeveloped

Highway Data

Roadway Variables:

$NumberofLanes := 2$		$LeftTurnImpact := 0$	0 = No, 1 = Yes
$Terrain := 2$	Level = 1, Rolling = 2	$Median := 0$	0 = No, 1 = Yes
$PostedSpeed := 50$	mi/h	$PresencePassingLane := 0$	0 = No, 1 = Yes
$SegLength := 4$	mi	$Spacing := 0$	mi
		$\%NPZ := 60$	

Traffic Variables:

$AADT := 14410$	$P_T := 4\%$	Percent trucks
$K := 0.096$	$BaseCapacity := 1700$	
$D := 0.60$	$LocalAdjustmentFactor := 1.0$	
$PHF := 0.91$		

LOS Computational Steps

1. Calculate Peak and Off-Peak Hour Volumes

$PeakHrVol := AADT \cdot K \cdot D$ $PeakHrVol = 830.0$ veh/h

$OffPeakHrVol := AADT \cdot K \cdot (1 - D)$ $OffPeakHrVol = 553.3$

2. Determine adjustment for the presence of a median and/or left turn lanes

Left Turn Impact Adjustment (LTadj) = -0.2 for left turn lanes NOT present, LTadj = 0 otherwise.

Median Adjustment (MedAdj) = 0.05 for median present, MedAdj = 0 otherwise.

Left Turn Lane:

$$\text{LTadj(LeftTurnImpact)} := \left| \begin{array}{l} \text{out} \leftarrow -0.2 \ \text{ if } \ \text{LeftTurnImpact} = 1 \\ \text{out} \leftarrow 0 \ \text{ if } \ \text{LeftTurnImpact} = 0 \\ \text{out} \end{array} \right.$$

$\text{LTadj(LeftTurnImpact)} = 0$ $\qquad$ $\text{LTadj} := \text{LTadj(LeftTurnImpact)}$ $\qquad$ $\text{LTadj} = 0$

Median:

$$\text{MedAdj(Median)} := \left| \begin{array}{l} \text{out} \leftarrow 0 \ \text{ if } \ \text{Median} = 0 \\ \text{out} \leftarrow 0.05 \ \text{ if } \ \text{Median} = 1 \\ \text{out} \end{array} \right.$$

$\text{MedAdj(Median)} = 0$ $\qquad$ $\text{MedAdj} := \text{MedAdj(Median)}$ $\qquad$ $\text{MedAdj} = 0$

Final Adjustment Value for Left Turn Lane and Median:

$\text{AdjMedLTL} := 1 + \text{LTadj} + \text{MedAdj}$ $\qquad$ $\text{AdjMedLTL} = 1$

3. Calculate Adjusted Volume (AdjVol)

Note: the PHF is assumed to be the same in the off-peak direction.

$\text{AdjPeakVol} := \dfrac{\text{PeakHrVol}}{\text{PHF} \cdot \text{AdjMedLTL}}$ $\qquad$ $\text{AdjPeakVol} = 912$ veh/h

$\text{AdjOffPeakVol} := \dfrac{\text{OffPeakHrVol}}{\text{PHF} \cdot \text{AdjMedLTL}}$ $\qquad$ $\text{AdjOffPeakVol} = 608$ veh/h

Calculations for Percent Time Spent Following (PTSF)

4. Determine E_T (Truck passenger car equivalency factor)

Note: '1' indicates analysis direction, '2' indicates opposing direction

$\text{VolIndexLow} := 900$ $\qquad$ $\text{valueLow} := 1.0$

$\text{VolIndexHigh} := 1000$ $\qquad$ $\text{valueHigh} := 1.0$

From Exhibit 15-18
HCM 2010

Interpolation:

$$E_{T1\_PTSF} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$$E_{T1\_PTSF} = 1.00$$

$VolIndexLow := 600$ $valueLow := 1.2$

$VolIndexHigh := 700$ $valueHigh := 1.0$

Interpolation:

$$E_{T2\_PTSF} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjOffPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$$E_{T2\_PTSF} = 1.18$$

5. Calculate heavy vehicle factor (f_{HV})

Note: All heavy vehicles are considered as trucks in HIGHPLAN

Equation 15-8 HCM 2010

$$f_{HV1\_PTSF} := \frac{1}{1 + P_T\cdot\left(E_{T1\_PTSF} - 1\right)} \qquad f_{HV1\_PTSF} = 1.00$$

$$f_{HV2\_PTSF} := \frac{1}{1 + P_T\cdot\left(E_{T2\_PTSF} - 1\right)} \qquad f_{HV2\_PTSF} = 0.99$$

6. Determine grade adjustment factor (f_G)

From Exhibit 15-16 HCM 2010

$VolIndexLow := 900$ $valueLow := 1.0$

$VolIndexHigh := 1000$ $valueHigh := 1.0$

Interpolation:

$$f_{G1\_PTSF} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$$f_{G1\_PTSF} = 1.00$$

$VolIndexLow := 600$ $valueLow := 0.97$

$VolIndexHigh := 700$ $valueHigh := 0.99$

Interpolation:

$$f_{G2\_PTSF} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjOffPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$f_{G2\_PTSF} = 0.97$

7. Calculate analysis and opposing direction volumes

Since the PHF was already accounted for in Step 5, the following equation is used:

Equation 15-7
HCM 2010

$$v_{d\_PTSF} := \frac{AdjPeakVol}{f_{G1\_PTSF} \cdot f_{HV1\_PTSF}} \qquad v_{d\_PTSF} = 912.1 \qquad \text{pc/h}$$

$$v_{o\_PTSF} := \frac{AdjOffPeakVol}{f_{G2\_PTSF} \cdot f_{HV2\_PTSF}} \qquad v_{o\_PTSF} = 630.4 \qquad \text{pc/h}$$

8. Determine values of coefficients 'a' and 'b' for HCM Equation 15-10

Note: This table uses opposing demand flow rate (pc/h)

$VolIndexLow := 600 \qquad valueLow := -0.0033$

$VolIndexHigh := 800 \qquad valueHigh := -0.0045$

From Exhibit 15-20
HCM 2010

Interpolation:

$$a := valueLow + (valueHigh - valueLow) \cdot \left(\frac{v_{o\_PTSF} - VolIndexLow}{VolIndexHigh - VolIndexLow} \right)$$

$a = -0.0035$

$VolIndexLow := 600 \qquad valueLow := 0.870$

$VolIndexHigh := 800 \qquad valueHigh := 0.833$

Interpolation:

$$b := valueLow + (valueHigh - valueLow) \cdot \left(\frac{v_{o\_PTSF} - VolIndexLow}{VolIndexHigh - VolIndexLow} \right)$$

$b = 0.8644$

9. Calculate base percent time spent following (BPTSF)

$$BPTSF_d := 100 \cdot \left(1 - e^{a \cdot v_{d\_PTSF}^{\,b}} \right) \qquad BPTSF_d = 71.6$$

Equation 15-10
HCM 2010

10. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-16

$v_{TwoWay} := v_{d\_PTSF} + v_{o\_PTSF}$ $\quad v_{TwoWay} = 1542.5$

$VolIndexLow := 1400$ $\quad valueLow := 25.4$

$VolIndexHigh := 2000$ $\quad valueHigh := 16.0$

From Exhibit 15-21
HCM 2010

Interpolation:

$$f_{np} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{v_{TwoWay} - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$f_{np} = 23.17$

11. Calculate percent time spent following (PTSF)

$$PTSF_d := BPTSF_d + f_{np}\cdot\left(\frac{v_{d\_PTSF}}{v_{TwoWay}}\right)$$

$PTSF_d = 85.3$

Equation 15-9
HCM 2010

Calculations for Average Travel Speed (ATS)

12. Determine E_T (Truck passenger car equivalency factor)

Note: '1' indicates analysis direction, '2' indicates opposing direction

$VolIndexLow := 900$ $\quad valueLow := 1.3$

$VolIndexHigh := 1000$ $\quad valueHigh := 1.3$

From Exhibit 15-11
HCM 2010

Interpolation:

$$E_{T1\_ATS} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$E_{T1\_ATS} = 1.30$

$VolIndexLow := 600$ $\quad valueLow := 1.7$

$VolIndexHigh := 700$ $\quad valueHigh := 1.6$

Interpolation:

$$E_{T2\_ATS} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{AdjOffPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$E_{T2\_ATS} = 1.69$

13. Calculate heavy vehicle factor (f_{HV})

Note: All heavy vehicles are considered as trucks in HIGHPLAN

$$f_{HV1\_ATS} := \frac{1}{1 + P_T \cdot (E_{T1\_ATS} - 1)} \qquad f_{HV1\_ATS} = 0.99$$

Equation 15-4
HCM 2010

$$f_{HV2\_ATS} := \frac{1}{1 + P_T \cdot (E_{T2\_ATS} - 1)} \qquad f_{HV2\_ATS} = 0.97$$

14. Determine grade adjustment factor (f_G)

$VolIndexLow := 900$ $valueLow := 1.0$

$VolIndexHigh := 1000$ $valueHigh := 1.0$

From Exhibit 15-9
HCM 2010

Interpolation:

$$f_{G1\_ATS} := valueLow + (valueHigh - valueLow) \cdot \left(\frac{AdjPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow} \right)$$

$f_{G1\_ATS} = 1.00$

$VolIndexLow := 600$ $valueLow := 0.97$

$VolIndexHigh := 700$ $valueHigh := 0.98$

Interpolation:

$$f_{G2\_ATS} := valueLow + (valueHigh - valueLow) \cdot \left(\frac{AdjOffPeakVol - VolIndexLow}{VolIndexHigh - VolIndexLow} \right)$$

$f_{G2\_ATS} = 0.97$

15. Calculate analysis and opposing direction volumes

Since the PHF was already accounted for in Step 5, the following equation is used:

Equation 15-3
HCM 2010

$$v_{d\_ATS} := \frac{AdjPeakVol}{f_{G1\_ATS} \cdot f_{HV1\_ATS}} \qquad v_{d\_ATS} = 923.1$$ pc/h

$$v_{o\_ATS} := \frac{AdjOffPeakVol}{f_{G2\_ATS} \cdot f_{HV2\_ATS}} \qquad v_{o\_ATS} = 643.7$$ pc/h

16. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 15-6

$FFS := PostedSpeed + 5 = 55$

$VolIndexLow := 600$ $valueLow := 1.6$

$VolIndexHigh := 800$ $valueHigh := 1.1$

From Exhibit 15-15
HCM 2010

Interpolation:

$$f_{np} := valueLow + (valueHigh - valueLow)\cdot\left(\frac{v_{o\_ATS} - VolIndexLow}{VolIndexHigh - VolIndexLow}\right)$$

$f_{np} = 1.49$

17. Calculate average travel speed (ATS)

$ATS_d := FFS - 0.00776\cdot(v_{d\_ATS} + v_{o\_ATS}) - f_{np}$ $ATS_d = 41.4$ mi/h

Equation 15-6
HCM 2010

18. Calculate Percentage of Free-Flow Speed (%FFS)

$$\%FFS := \frac{ATS_d}{FFS}\cdot 100$$

$\%FFS = 75.2$

19. Calculate Free-Flow Delay

$$FFDelay := \left(\frac{SegLength}{ATS_d} - \frac{SegLength}{FFS}\right)\cdot 3600$$

$FFDelay = 86.4$ sec/veh

20. Calculate LOS Threshold Delay

$$LOSspeedthresh(AreaType) := \begin{cases} \text{return } 37 \text{ if } AreaType = 1 \\ \text{return } 50 \text{ if } AreaType = 2 \lor AreaType = 3 \lor AreaType = 4 \end{cases}$$

$LOSspeedthresh(AreaType) = 50$

$$LOSDelay := \left(\frac{SegLength}{ATS_d} - \frac{SegLength}{LOSspeedthresh(AreaType)}\right)\cdot 3600$$

$LOSDelay = 60.2$ sec/veh

21. Calculate v/c ratio

Use the higher volumes between PTSF and ATS, which is ATS in this case

Note: In the software, the v/c ratios are checked to make sure they are not greater than 1.0 before proceeding with the rest of the analysis. If one of the v/c ratios is greater than 1.0, the analysis stops and LOS is set to 'F'.

$$vcratioTwoWay := \frac{v_{d\_ATS} + v_{o\_ATS}}{BaseCapacity \cdot \left(\frac{3200}{1700}\right)} \qquad vcratioTwoWay = 0.49$$

$$vcratioOneWay := \frac{v_{d\_ATS}}{BaseCapacity} \qquad vcratioOneWay = 0.54$$

$$vcratio := \max(vcratioTwoWay, vcratioOneWay) \qquad vcratio = 0.54$$

22. Determine Class

$$ClassCalc(AreaType) := \begin{vmatrix} \text{return } 1 \text{ if } AreaType = 4 \\ \text{return } 3 \text{ if } AreaType = 1 \vee AreaType = 2 \vee AreaType = 3 \end{vmatrix}$$

$$Class := ClassCalc(AreaType) \qquad Class = 3$$

23. Determine Level of Service

If Class = 1, the lower LOS governs

From Exhibit 15-3 HCM 2010

$$
\mathrm{LosCalc}(\mathrm{Class},\mathrm{PTSF},\mathrm{ATS},\mathrm{FFS}) := \left|
\begin{array}{l}
\text{if } \mathrm{Class} = 1 \\
\quad \left|
\begin{array}{l}
out_1 \leftarrow \text{"A"} \quad \text{if } \mathrm{PTSF} \le 35 \\
out_1 \leftarrow \text{"B"} \quad \text{if } 35 < \mathrm{PTSF} \le 50 \\
out_1 \leftarrow \text{"C"} \quad \text{if } 50 < \mathrm{PTSF} \le 65 \\
out_1 \leftarrow \text{"D"} \quad \text{if } 65 < \mathrm{PTSF} \le 80 \\
out_1 \leftarrow \text{"E"} \quad \text{if } \mathrm{PTSF} > 80 \\
out_2 \leftarrow \text{"A"} \quad \text{if } \mathrm{ATS} > 55 \\
out_2 \leftarrow \text{"B"} \quad \text{if } 50 < \mathrm{ATS} \le 55 \\
out_2 \leftarrow \text{"C"} \quad \text{if } 45 < \mathrm{ATS} \le 50 \\
out_2 \leftarrow \text{"D"} \quad \text{if } 40 < \mathrm{ATS} \le 45 \\
out_2 \leftarrow \text{"E"} \quad \text{if } \mathrm{ATS} \le 40 \\
out \leftarrow \begin{pmatrix} out_1 \\ out_2 \end{pmatrix}
\end{array} \right. \\
\text{if } \mathrm{Class} = 2 \\
\quad \left|
\begin{array}{l}
out \leftarrow \text{"A"} \quad \text{if } \mathrm{PTSF} \le 40 \\
out \leftarrow \text{"B"} \quad \text{if } 40 < \mathrm{PTSF} \le 55 \\
out \leftarrow \text{"C"} \quad \text{if } 55 < \mathrm{PTSF} \le 70 \\
out \leftarrow \text{"D"} \quad \text{if } 70 < \mathrm{PTSF} \le 85 \\
out \leftarrow \text{"E"} \quad \text{if } \mathrm{PTSF} > 80 \\
out
\end{array} \right. \\
\text{if } \mathrm{Class} = 3 \\
\quad \left|
\begin{array}{l}
out \leftarrow \text{"A"} \quad \text{if } \dfrac{\mathrm{ATS}}{\mathrm{FFS}} > 0.917 \\
out \leftarrow \text{"B"} \quad \text{if } 0.833 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.917 \\
out \leftarrow \text{"C"} \quad \text{if } 0.750 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.833 \\
out \leftarrow \text{"D"} \quad \text{if } 0.667 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.750 \\
out \leftarrow \text{"E"} \quad \text{if } 0.583 < \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.667 \\
out \leftarrow \text{"F"} \quad \text{if } \dfrac{\mathrm{ATS}}{\mathrm{FFS}} \le 0.583 \\
out
\end{array} \right. \\
out
\end{array} \right.
$$

$$
\mathrm{LOS} := \max\left(\mathrm{LosCalc}\left(\mathrm{Class}, \mathrm{PTSF}_d, \mathrm{ATS}_d, \mathrm{FFS}\right)\right)
$$

$$
\mathrm{LOS} = \text{"C"}
$$

Service Volumes Check

From Exhibit 15-3 HCM 2000, for a Class III highway the percent free flow speed (%FFS) threshold for LOS C is 0.75.

Using the procedure documented above, the following results are obtained for the displayed 830 veh/h peak direction service volume.

$$\text{InputAADT} := \text{Round}\left(\frac{830}{K \cdot D}, 10\right) = 14410$$

$ATS_d = 41.351$ mi/h

$FFS = 55$ mi/h

$$\frac{ATS_d}{FFS} = 0.752$$

Thus, the maximum service volume (AADT) for LOS C for the conditions in the example calculations file is ~14,410.

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.

$\text{NoPassingSV} := 830$ veh/h

$\text{Spacing} := 2$ miles

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

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

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

$\text{PassingSV} = 1240$ 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.

Appendix D
Calculations Documentation for HIGHPLAN (Multilane)

HIGHPLAN Computational Methodology

Dr. Scott Washburn
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Transportation Research Center

For Version 7/19/2012

Multilane Methodology

Inputs

Project Properties

Roadway Information:

AreaType := 2   1 = Urbanized, 2 = Transitioning/Urban, 3 = Rural Developed, 4 = Rural Undeveloped

Highway Data

Roadway Variables:

NumberofLanes := 4

Terrain := 2   Level = 1, Rolling = 2

PostedSpeed := 45   mi/h

SegLength := 5   mi

LeftTurnImpact := 1   0 = No, 1 = Yes

Median := 0   0 = No, 1 = Yes

Traffic Variables:

AADT := 39500

K := 0.095

D := 0.55

PHF := 0.925

P_T := 2%   Percent trucks

BaseCapacity := 2000

LocalAdjustmentFactor := 1.0

LOS Computational Steps

1. Calculate DDHV (Design Directional Hour Volume)

$DDHV := AADT \cdot K \cdot D$ $DDHV = 2064$

2. Determine E_T (Truck passenger car equivalency factor)

$$PCE(Terrain) := \begin{vmatrix} out \leftarrow 1.5 \text{ if } Terrain = 1 \\ out \leftarrow 2.5 \text{ if } Terrain = 2 \\ out \end{vmatrix}$$

From Exhibit 14-12
HCM 2010

$PCE(Terrain) = 2.5$ $E_T := PCE(Terrain)$ $E_T = 2.5$

3. Calculate heavy vehicle factor (f_{HV})

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)}$$ $f_{HV} = 0.971$

Equation 14-4
HCM 2010

4. Calculate Base Analysis Volume (v_p)

$LAF := LocalAdjustmentFactor$

$$v_p := \frac{DDHV}{PHF \cdot \frac{NumberofLanes}{2} \cdot f_{HV} \cdot LAF}$$ $v_p = 1149.1$ veh/h

Equation 14-3
HCM 2010

5. Determine adjustment for the presence of a median and/or left turn lanes

Left Turn Lane Adjustment (LTadj) = -0.2 for left turn lanes NOT present, LTadj = 0 otherwise.
Median Adjustment (MedAdj) = -0.05 for no median present, MedAdj = 0 otherwise. Note:
The presence of a median, but no left turn lanes is not a valid option per FDOT guidance.

$LTI := LeftTurnImpact$

$$LTadj(LTI) := \begin{vmatrix} out \leftarrow -0.2 \text{ if } LTI = 1 \\ out \leftarrow 0 \text{ if } LTI = 0 \\ out \end{vmatrix}$$

$$MedAdj(Median) := \begin{vmatrix} out \leftarrow -0.05 \text{ if } Median = 0 \\ out \leftarrow 0 \text{ if } Median = 1 \\ out \end{vmatrix}$$

$LTadj(LeftTurnImpact) = -0.2$

$LTadj := LTadj(LeftTurnImpact)$

$LTadj = -0.2$

$MedAdj(Median) = -0.05$

$MedAdj := MedAdj(Median)$

$MedAdj = -0.05$

Final Adjustment Value for Left Turn Lane and Median:

$AdjMedLTL := (1 + LTadj + MedAdj)$ $AdjMedLTL = 0.75$

6. Calculate Adjusted Analysis Volume (AdjVol)

$$AdjVol := \frac{v_p}{AdjMedLTL}$$

$AdjVol = 1532.1$ veh/h $V := AdjVol$ $V = 1532.1$ veh/h

7. Determine Average Passenger Car Speed

$FFS := PostedSpeed + 5 \qquad FFS = 50$

Exhibit 14-3
HCM 2010

$$Speed(FFS, AdjVol) := \begin{array}{|l} out \leftarrow FFS \ \text{ if } AdjVol \le 1400 \\ \text{if } AdjVol > 1400 \\ \quad \begin{array}{|l} out \leftarrow FFS - \left(\frac{3}{10}\cdot FFS - 13\right)\cdot\left(\frac{AdjVol - 1400}{28\cdot FFS - 880}\right)^{1.31} \ \text{ if } FFS > 55 \\ out \leftarrow FFS - \left(\frac{34}{205}\cdot FFS - \frac{219}{41}\right)\cdot\left(\frac{AdjVol - 1400}{\frac{171}{5}\cdot FFS - 1181}\right)^{1.31} \ \text{ if } 50 < FFS \le 55 \\ out \leftarrow FFS - \left(\frac{10}{43}\cdot FFS - \frac{350}{43}\right)\cdot\left(\frac{AdjVol - 1400}{33\cdot FFS - 1050}\right)^{1.31} \ \text{ if } 45 < FFS \le 50 \\ out \leftarrow FFS - \left(\frac{1}{5}\cdot FFS - \frac{56}{9}\right)\cdot\left(\frac{AdjVol - 1400}{36\cdot FFS - 1120}\right)^{1.31} \ \text{ if } FFS = 45 \end{array} \end{array}$$

$Speed(FFS, AdjVol) = 49.5 \qquad S := Speed(FFS, AdjVol) \qquad S = 49.52$ mi/h

8. Calculate Percentage of Free-Flow Speed (%FFS)

$$\%FFS := \frac{S}{FFS}\cdot 100 \qquad \%FFS = 99.0$$

9. Calculate Free-Flow Delay

$$FFDelay := \left(\frac{SegLength}{S} - \frac{SegLength}{FFS}\right)\cdot 3600 \qquad FFDelay = 3.5$$ sec/veh

10. Calculate LOS Threshold Delay

$$LOSspeedthresh(AreaType) := \begin{array}{|l} return\ 53 \ \text{ if } AreaType = 1 \\ return\ 60 \ \text{ if } AreaType = 2 \vee AreaType = 3 \vee AreaType = 4 \end{array}$$

$LOSspeedthresh(AreaType) = 60$

$$LOSDelay := \left(\frac{SegLength}{S} - \frac{SegLength}{LOSspeedthresh(AreaType)}\right)\cdot 3600 \qquad LOSDelay = 63.5$$ sec/veh

11. Calculate v/c ratio

$$vcratio := \frac{V}{BaseCapacity}$$ $vcratio = 0.77$

12. Calculate density

$$Density := \frac{AdjVol}{S}$$ Equation 21-5 HCM 2000 $Density = 30.9$ pc/mi/ln

Determine Level of Service

LOS Thresholds (FDOT specific)

Rural Developed and Rural Undeveloped	Urbanized and Transitioning
A <= 6	A <= 10
B <= 14	B <= 17
C <= 22	C <= 24
D <= 29	D <= 31
E <= 39 for FFS = 45	E <= 39 for FFS = 45
E <= 37 for FFS = 50	E <= 37 for FFS = 50
E <= 35 for FFS = 55	E <= 35 for FFS = 55
E <= 34 for FFS > 60	E <= 34 for FFS > 60

$LOS := D$

Service Volumes Check

The density threshold for Transitioning area type and LOS D is 31 pc/mi/ln

Using the procedure documented above, the following results are obtained for the displayed 1750 veh/h peak direction service volume.

$$InputAADT := Round\left(\frac{2064}{K \cdot D}, 10\right) = 39500$$

$AdjVol = 1532$ veh/h

$S = 49.52$ mi/h

$Density = 30.9$ pc/mi/ln

Thus, the maximum service volume (AADT) for LOS D for the conditions in the example calculations file is ~39,500.

Appendix E
Calculations Documentation for HIGHPLAN (Two-Lane Facility)

HIGHPLAN Computational Methodology

For Version 9/24/2012

Dr. Scott Washburn
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Transportation Research Center

Two-Lane Facility Analysis, Example 1

Inputs and Initial Computations.

1. Input Roadway and Traffic Data.

Roadway Data

Class III Highways (The new %Delay LOS criteria are a function of highway class)

$AnalysisType := 0$ 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

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

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

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

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

$v_{LT} := 48$ $v_{RT} := 48$ $\%LT := \frac{\frac{v_{LT}}{PHF}}{v_p} \cdot 100$ $\%LT = 8$

Signal Data

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

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

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

$BaseCapacity := 1700$

2. Determine segment lengths

Upstream effective length of signal (L_{eff_up})

$$L_{eff\_up} := 266.66 + 3.047 \cdot \left(\frac{v_p}{100}\right)^2 + 8.626 \cdot C - 0.972 \cdot \left(\frac{v_p}{100}\right) \cdot \%LT - 14.102 \cdot C \cdot g\_C$$

$L_{eff\_up} = 353.923$ (ft) $L_{eff\_up} := \frac{L_{eff\_up}}{5280}$ $L_{eff\_up} = 0.067$ (mi)

Length of basic two-lane segment upstream of signal (L_1)

$L_1 := L_{up} - L_{eff\_up}$ $L_1 = 2.933$ (mi)

Downstream effective length of signal (L_{eff_down})

$$L_{eff\_down} := 701.34 + 51.016 \cdot \left(\frac{v_p}{100}\right) + 42.353 \cdot \%HV_{EB} + 13.833 \cdot C - 1.701 \cdot \left(\frac{v_p}{100}\right) \cdot \%LT - 16.760 \cdot C \cdot g\_C$$

$L_{eff\_down} = 1489.3$ (ft) $L_{eff\_down} := \frac{L_{eff\_down}}{5280}$ $L_{eff\_down} = 0.282$ (mi)

Length of intersection influence area ($L_{intersecion}$)

$L_{intersection} := L_{eff\_up} + L_{eff\_down} = 0.349$ (mi)

Length of basic two-lane segment downstream of signal (L_2)

$L_2 := L_T - L_1 - L_{intersection} = 3.718$ (mi)

3. Estimate the free-flow speed

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

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

$ATS_1 := 49.62$ mi/h

5. Calculate control delay at the signalized intersection influence area

$ControlDelay := 11.1$ sec/veh See signal delay calculations section below

6. Determine average travel speed on the unaffected downstream segment

$ATS_2 := 49.62$ mi/h

7. Determine the delay of every segment

$L_1 = 2.933$ $S_1 := ATS_1$ $S_1 = 49.62$ $FFS = 60$

$$D_1 := \left(\frac{L_1}{S_1} - \frac{L_1}{FFS}\right) \cdot 3600 \qquad D_1 = 36.813$$

$L_{intersection} = 0.349$

$D_{intersection} := ControlDelay$ $D_{intersection} = 11.1$

$L_2 = 3.718$ $S_2 := ATS_2$ $S_2 = 49.62$ $FFS = 60$

$$D_2 := \left(\frac{L_2}{S_2} - \frac{L_2}{FFS}\right) \cdot 3600 \qquad D_2 = 46.665$$

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

1. The total length of the facility:

$L_t := L_1 + L_{intersection} + L_2$ $L_t = 7$ mi

2. The total delay of the facility:

$D_T := D_1 + D_{intersection} + D_2$ $D_T = 94.578$ sec/veh

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

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

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

$$PTD := \left(\frac{D_T}{T_{tFFS}}\right) \cdot 100 \qquad PTD = 22.52$$ (%)

9. Determine the Level of Service

$$LOS(PTD) := \begin{array}{|l} los \leftarrow "A" \text{ if } PTD \le 9.5 \\ los \leftarrow "B" \text{ if } 9.5 < PTD \le 21.5 \\ los \leftarrow "C" \text{ if } 21.5 < PTD \le 36.5 \\ los \leftarrow "D" \text{ if } 36.5 < PTD \le 55.5 \\ los \leftarrow "E" \text{ if } PTD > 55.5 \end{array}$$

New PD LOS criteria for Class III highways

$LOS(PTD) = "C"$

Signal Delay Calculations

a. Calculate volume to capacity ratio (v/c)

$E_T := 2.3$

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 0.939$$

$$P_{RT} := \frac{\frac{v_{RT}}{PHF}}{v_p - \frac{v_{LT}}{PHF}} \qquad P_{RT} = 0.087$$

$f_{RT} := 1.0 - 0.15 \cdot P_{RT}$ $f_{RT} = 0.987$

shared lane equation instead of single lane

$BaseSatFlowRate := 1900$

$AdjSatFlowRate := BaseSatFlowRate \cdot f_{HV} \cdot f_{RT}$ $AdjSatFlowRate = 1760.8$

$c := AdjSatFlowRate \cdot g\_C$ $c = 1056.5$

$$ThruMvmtFlowRate_1 := v_p \cdot \left[1 - \left(\frac{\%LT}{100}\right)\right] \qquad ThruMvmtFlowRate_1 = 581.1$$

$$vc_1 := \frac{ThruMvmtFlowRate_1}{c \cdot 1} \qquad vc_1 = 0.55$$

b. Calculate uniform delay (d_1)

$RedTime := C - (C \cdot g\_C) = 36$

$$QueueClearTime := \frac{\frac{ThruMvmtFlowRate_1}{3600} \cdot RedTime}{\frac{AdjSatFlowRate}{3600} - \frac{ThruMvmtFlowRate_1}{3600}} = 17.7$$

$$TotalDelay := 0.5 \cdot (RedTime)^2 \cdot \left(\frac{ThruMvmtFlowRate_1}{3600}\right) + 0.5 \cdot \left(\frac{ThruMvmtFlowRate_1}{3600}\right) \cdot (RedTime) \cdot QueueClearTime = 156.$$

$$d_{1\_1} := \frac{TotalDelay}{\left(\frac{ThruMvmtFlowRate_1}{3600}\right) \cdot C} = 10.7$$

c. Calculate incremetal delay (d_2)

Determine k, signal controller mode delay adjustment factor

fully-actuated mode assumed

$PassageTime := 2.0$

$$k_{min} := max\left(-0.375 + 0.354 \cdot PassageTime - 0.091 \cdot PassageTime^2 + 0.00889 \cdot PassageTime^3, 0.04\right)$$

$$k := min\left[max\left[\left(1 - 2 \cdot k_{min}\right) \cdot \left(vc_1 - 0.5\right) + k_{min}, k_{min}\right], 0.5\right]$$

$k = 0.086$

$I := 1.0$ random arrivals assumed, given relatively long spacing between signals

$T := 0.25$

$$d_{2\_1} := 900 \cdot T \cdot \left[\left(vc_1 - 1\right) + \sqrt{\left(vc_1 - 1\right)^2 + \frac{8 \cdot k \cdot I \cdot vc_1}{T \cdot c \cdot 1}}\right]$$

$d_{2\_1} = 0.358$

d. Calculate the overall average delay

$AvgDelay_1 := d_{1\_1} + d_{2\_1}$

$AvgDelay_1 = 11.1$

Appendix F
Calculations Documentation for FREEPLAN
Excluding Toll Plaza Analysis

Basic Methodology

Input Values

Traffic

$FwyVol := 3036 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65$

$\%Trucks_F := 5 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.05$$

**FwyVolNew and %Trucks$_{FNew}$ from the previous upstream segment are the input values for FwyVol and %Trucks$_F$ (if there is a previous upstream segment).*

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.87$

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

$AreaType := 2$ 1 = Rural, 2 = Urban

**FREEPLAN determines IntDens by counting each on- and off-ramp as 1/2 interchange each and adds them across the entire facility. Then, it divides that total number of interchanges by the total length of the facility.*

Find f_{HV} (using Exhibit 23-8 and Eq. 23-3)

$$E_T(Terrain) := \begin{array}{|l} out \leftarrow 1.5 \text{ if } Terrain = 1 \\ out \leftarrow 2.5 \text{ if } Terrain = 2 \\ out \leftarrow 4.5 \text{ if } Terrain = 3 \\ out \end{array} \qquad E_R(Terrain) := \begin{array}{|l} out \leftarrow 1.2 \text{ if } Terrain = 1 \\ out \leftarrow 2.0 \text{ if } Terrain = 2 \\ out \leftarrow 4.0 \text{ if } Terrain = 3 \\ out \end{array}$$

$E_T(Terrain) = 1.5 \quad E_T := E_T(Terrain) \qquad E_R(Terrain) = 1.2 \quad E_R := E_R(Terrain)$

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9756$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1091.9 \text{ pc/h/ln}$$

Determine S

$$Eqn1 := 75 - 0.00001107 \cdot (v_p - 1000)^2$$

$$Eqn2 := 70 - 0.00001160 \cdot (v_p - 1200)^2$$

$$Eqn3 := 65 - 0.00001418 \cdot (v_p - 1400)^2$$

$$Eqn4 := 60 - 0.00001816 \cdot (v_p - 1600)^2$$

$$Eqn5 := 55 - 0.00002469 \cdot (v_p - 1800)^2$$

$$S := \left| \begin{array}{l} out \leftarrow Eqn1 \ \text{ if } \ FFS = 75 \wedge v_p > 1000 \\ out \leftarrow Eqn2 \ \text{ if } \ FFS = 70 \wedge v_p > 1200 \\ out \leftarrow Eqn3 \ \text{ if } \ FFS = 65 \wedge v_p > 1400 \\ out \leftarrow Eqn4 \ \text{ if } \ FFS = 60 \wedge v_p > 1600 \\ out \leftarrow Eqn5 \ \text{ if } \ FFS = 55 \wedge v_p > 1800 \\ out \leftarrow FFS \end{array} \right.$$

$S = 65.0$

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 16.8$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

$$LOS(D) := \left| \begin{array}{l} out \leftarrow \text{"F"} \ \text{ if } \ D > 45 \\ out \leftarrow \text{"E"} \ \text{ if } \ 45 \ge D > 35 \\ out \leftarrow \text{"D"} \ \text{ if } \ 35 \ge D > 26 \\ out \leftarrow \text{"C"} \ \text{ if } \ 26 \ge D > 18 \\ out \leftarrow \text{"B"} \ \text{ if } \ 18 \ge D > 11 \\ out \leftarrow \text{"A"} \ \text{ if } \ 11 \ge D \\ out \end{array} \right.$$

$LOS(D) = \text{"B"}$

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 3036$

$\%Trucks_{FNew} := \%Trucks_F = 5$

**FwyVolNew and %Trucks$_{FNew}$ are the input values for FwyVol and %Trucks$_F$ for the next downstream segment if there is one. If the next segment is a weave, then %Trucks$_{FNew}$ is the input value for %Trucks_FF and %Trucks_FR.*

Off-Ramp Methodology

Step 1. Data Inputs and Volume Adjusments

**FwyVolNew and %Trucks$_{FNew}$ from the previous upstream segment are the input values for FwyVol and %Trucks$_F$ (if there is a previous upstream segment).*

A. Inputs

$FwyVol := 3036$ veh/h $RampVol := 300$ veh/h

$\%Trucks_F := 5$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 65.0$ mi/h Average speed on immediate upstream segment

$NumLanes := 3$ Number of mainline freeway lanes $NRamp := 1$ Number of lanes on ramp roadway

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

$L_{seg} := 1500$ ft $L_{prev} := 5280$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 3390 \text{ ft}$$

Distance from midpoints of upstream and subject segments

$L_D := 450$ ft Total length of Deceleration Lane

$S_{FR} := 40$ mi/h Freeflow speed of the ramp at the junction point

$AdjUp := 0$ $AdjDn := 1$ 0 = none, 1 = on-ramp, 2 = off-ramp for Adjacent Upstream/Downstream Ramps

$L_{up} := 5280$ ft $L_{down} := 500$ ft

$VolumeUp := 0$ veh/h Volume on adjacent upstream ramp

$VolumeDown := 700$ veh/h Volume on adjacent downstream ramp

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

$$E_T(Terrain) := \begin{cases} out \leftarrow 1.5 & \text{if } Terrain = 1 \\ out \leftarrow 2.5 & \text{if } Terrain = 2 \\ out \leftarrow 4.5 & \text{if } Terrain = 3 \end{cases} \qquad E_R(Terrain) := \begin{cases} out \leftarrow 1.2 & \text{if } Terrain = 1 \\ out \leftarrow 2.0 & \text{if } Terrain = 2 \\ out \leftarrow 4.0 & \text{if } Terrain = 3 \end{cases}$$

$E_T(Terrain) = 1.5$ $E_R(Terrain) = 1.2$

$E_T := E_T(Terrain)$ $E_T = 1.5$ $E_R := E_R(Terrain)$ $E_R = 1.2$

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} \qquad f\_HV_F = 0.976$$

$$f\_HV_R := \frac{100}{100 + \%Trucks_R(E_T - 1) + \%RV_R(E_R - 1)} \qquad f\_HV_R = 0.99$$

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3276 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 319 \text{ pc/h}$$

$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p}$ $V_u = 0$ pc/h $V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p}$ $V_d = 744$ pc/h

Step 2. Determine the Approaching Flow Rate in Lanes 1 and 2

A. Equilibrium Seperation Distance for Adjacent Upstream On-Ramp or Downstream Off-Ramps on a Six Lane Freeway

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 0 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 802 \text{ ft}$$

B. Estimating Proportion of Freeway Vehicles Remaining in lanes 1 and 2

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.663$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.589$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.732$$

$P_{FD}(Numlanes) :=$

- out ← 1.00 if NumLanes = 2
- out ← Eqn1 if $AdjUp = 0 \wedge AdjDn = 0 \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 0 \wedge AdjDn = 1 \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- out ← Eqn3 if $AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3$
- out ← Eqn2 if $AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 2 \wedge AdjDn = 0 \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3$
- out ← Eqn2 if $AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3$
- out ← max(Eqn2, Eqn3) if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- out ← max(Eqn2, Eqn1) if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- out ← max(Eqn3, Eqn1) if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 2 \wedge AdjDn = 1 \wedge NumLanes = 3$
- out ← Eqn1 if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- out ← Eqn3 if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- out ← 0.436 if NumLanes = 4

$P_{FD} := P_{FD}(NumLanes)$ $P_{FD} = 0.663$

C. Estimating Flow in Lanes 1 and 2

$V_{12} := V_r + (V_f - V_r) \cdot P_{FD}$ $\qquad V_{12} = 2281$ pc/h

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $\qquad V_3 = 995$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $\qquad V_{av34} = 498$ pc/h

$$
V12a(\text{NumLanes}) := \left|
\begin{array}{l}
\text{out} \leftarrow V_{12} \ \text{ if } \ \text{NumLanes} = 2 \\
\text{out} \leftarrow V_f - 2700 \ \text{ if } \ V_3 > 2700 \wedge V_3 \le 1.5 \cdot \frac{V_{12}}{2} \vee \text{NumLanes} = 3 \\
\text{out} \leftarrow \frac{V_f}{1.75} \ \text{ if } \ V_3 \le 2700 \wedge V_3 > 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 3 \\
\text{out} \leftarrow \max\left(V_f - 2700, \frac{V_f}{1.75}\right) \ \text{ if } \ V_3 > 2700 \wedge V_3 > 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 3 \\
\text{out} \leftarrow V_{12} \ \text{ if } \ V_3 \le 2700 \wedge V_3 \le 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 3 \\
\text{out} \leftarrow V_f - 5400 \ \text{ if } \ V_{av34} > 2700 \wedge V_{av34} \le 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 4 \\
\text{out} \leftarrow \frac{V_f}{2.50} \ \text{ if } \ V_{av34} \le 2700 \wedge V_{av34} > 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 4 \\
\text{out} \leftarrow \max\left(V_f - 5400, \frac{V_f}{2.50}\right) \ \text{ if } \ V_{av34} > 2700 \wedge V_{av34} > 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 4 \\
\text{out} \leftarrow V_{12} \ \text{ if } \ V_{av34} \le 2700 \wedge V_{av34} \le 1.5 \cdot \frac{V_{12}}{2} \wedge \text{NumLanes} = 4
\end{array}
\right.
$$

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(\text{NumLanes})$ $\qquad V_{12} = 2281$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

$$\text{CapUpFreewaySegment}(\text{NumLanes}, \text{FFS}) := \left|\begin{array}{l} \text{out} \leftarrow 4800 \quad \text{if} \quad \text{FFS} \geq 70 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4700 \quad \text{if} \quad \text{FFS} = 65 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4600 \quad \text{if} \quad \text{FFS} = 60 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4600 \quad \text{if} \quad \text{FFS} = 55 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 7200 \quad \text{if} \quad \text{FFS} = 70 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 7050 \quad \text{if} \quad \text{FFS} = 65 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 6900 \quad \text{if} \quad \text{FFS} = 60 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 6750 \quad \text{if} \quad \text{FFS} = 55 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 9600 \quad \text{if} \quad \text{FFS} = 70 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9400 \quad \text{if} \quad \text{FFS} = 65 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9200 \quad \text{if} \quad \text{FFS} = 60 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9000 \quad \text{if} \quad \text{FFS} = 55 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 2400 \cdot \text{NumLanes} \quad \text{if} \quad \text{FFS} = 70 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2350 \cdot \text{NumLanes} \quad \text{if} \quad \text{FFS} = 65 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2300 \cdot \text{NumLanes} \quad \text{if} \quad \text{FFS} = 60 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2250 \cdot \text{NumLanes} \quad \text{if} \quad \text{FFS} = 55 \wedge \text{NumLanes} > 4 \end{array}\right.$$

$\text{CapUpFreewaySegment}(\text{NumLanes}, \text{FFS}) = 7050$ Capacity of Ramp Freeway Junction

$\text{MaxV12} = 4400$ Maximum Desirable Flow Rate Entering Merge Influence Area

$$\text{CapacityRampRoadway} := \left|\begin{array}{l} \text{out} \leftarrow 2200 \quad \text{if} \quad (\text{NRamp} = 1) \wedge (S_{FR} > 50) \\ \text{out} \leftarrow 2100 \quad \text{if} \quad (\text{NRamp} = 1) \wedge (40 < S_{FR} \leq 50) \\ \text{out} \leftarrow 2000 \quad \text{if} \quad (\text{NRamp} = 1) \wedge (30 < S_{FR} \leq 40) \\ \text{out} \leftarrow 1900 \quad \text{if} \quad (\text{NRamp} = 1) \wedge (20 \leq S_{FR} \leq 30) \\ \text{out} \leftarrow 1800 \quad \text{if} \quad (\text{NRamp} = 1) \wedge (20 > S_{FR}) \\ \text{out} \leftarrow 4400 \quad \text{if} \quad (\text{NRamp} = 2) \wedge (S_{FR} > 50) \\ \text{out} \leftarrow 4200 \quad \text{if} \quad (\text{NRamp} = 2) \wedge (40 < S_{FR} \leq 50) \\ \text{out} \leftarrow 4000 \quad \text{if} \quad (\text{NRamp} = 2) \wedge (30 < S_{FR} \leq 40) \\ \text{out} \leftarrow 3800 \quad \text{if} \quad (\text{NRamp} = 2) \wedge (20 \leq S_{FR} \leq 30) \\ \text{out} \leftarrow 3600 \quad \text{if} \quad (\text{NRamp} = 2) \wedge (20 > S_{FR}) \end{array}\right.$$

$\text{CapacityRampRoadway} = 2000$

$V_f = 3276$ pc/h Volume immediatley upstream of off-ramp influence area

Ramp Freeway Junction Checkpoint

Volume immediatley upstream of off-ramp influence area is chekced against freeway capacity. Failure of ramp freeway junction checkpoint (i.e. demand exceeds capacity) results in LOS F

Ramp Roadway Capacity Checkpoint	If the off-ramp demand flow rate (Vr) exceeds the capacity of the off-ramp, LOS F prevails.
Maximum Desirable Flow Entering Ramp Influence Area Checkpoint	While the V12 values is checked against the maximum desirable, failure does not result in assignment of LOS F. Failing this checkpoint generally means that there will be more turbulance in influence area than predicted by this methodology. Thus, predicted densities are most likely lower than those that will exist, and predicted speeds are most likely to be predicted as higher than those that will actually occur.

Step 4. Determine Speeds in the Vicinity of Ramp-Freeway Junction

A. Average Speed in the Ramp Influence Area

$$S_R := FFS - (FFS - 42)\cdot(0.883 + 0.00009\cdot V_r - 0.013\cdot S_{FR})$$

$S_R = 55.99$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$N_o := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{N_o}$$

$V_{OA} = 995$

$$S_O(V_{OA}) := \begin{cases} out \leftarrow 1.097\cdot FFS & \text{if } V_{OA} < 1000 \\ out \leftarrow 1.097\cdot FFS - 0.0039\cdot(V_{OA} - 1000) & \text{if } 1000 \le V_{OA} \end{cases}$$

$$S_O := S_O(V_{OA})$$

$S_O = 71.30$ mi/h

C. Average Speed for Off-Ramp Junction

$$S_{avg} := \frac{V_{12} + V_{OA}\cdot N_o}{\left(\frac{V_{12}}{S_R}\right) + \left(\frac{V_{OA}\cdot N_o}{S_O}\right)}$$

$S_{avg} = 59.9$ mi/h

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev})\cdot e^{(-0.00162\cdot L_{midpnts})}$$

$S_{max} = 65.0$ mi/h

$$S := \begin{cases} S_{avg} & \text{if } S_{avg} \le S_{max} \\ S_{max} & \text{if } S_{avg} > S_{max} \end{cases}$$

$S = 59.9$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $\quad Density_R = 19.8$ pc/mi/ln

B. Density in Outer Lanes

$Density_O := \frac{V_{OA}}{S_O}$ $\quad Density_O = 14$ pc/mi/ln

C. Density of Entire Cross-Section

$$Density := \begin{cases} out \leftarrow Density_R & \text{if } NumLanes \le 2 \\ out \leftarrow \frac{[Density_R \cdot (2) + Density_O \cdot (NumLanes - 2)]}{NumLanes} & \text{if } NumLanes > 2 \end{cases}$$

$Density = 17.9$ pc/mi/ln

D. Level of Service

$$LOS(Density) := \begin{cases} out \leftarrow \text{"A"} & \text{if } 0 \le Density \le 10 \\ out \leftarrow \text{"B"} & \text{if } 10 < Density \le 20 \\ out \leftarrow \text{"C"} & \text{if } 20 < Density \le 28 \\ out \leftarrow \text{"D"} & \text{if } 28 < Density \le 35 \\ out \leftarrow \text{"E"} & \text{if } 35 < Density \end{cases}$$

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

Step 6. Determine Input Vol and %HV for Next Downstream Segment

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 2884.2$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 294$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2590.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 151.8$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 6$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 145.8$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2736$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.3289$$

**FwyVolNew and $\%Trucks_{FNew}$ are the input values for FwyVol and $\%Trucks_F$ for the next downstream segment if there is one. If the next segment is a weave, then $\%Trucks_{FNew}$ is the input value for %Trucks_FF and %Trucks_FR.*

Weaving Methodology

Step 1. Data Inputs

**FwyVolNew and %Trucks$_{FNew}$ from the previous upstream segment are the input values for SegInputVol and SegInput%HV if there is a previous upstream segment.*

OnRampVol := 700 OffRampVol := 455 SegInputVol := 2736 Int_Density := 0.87 int/mi

OnRamp%HV := 2 OffRamp%HV := 2 SegInput%HV := 5.3289

**FREEPLAN determines IntDens by counting each on- and off-ramp as 1/2 interchange each and adds them across the entire facility. Then, it divides that total number of interchanges by the total length of the facility.*

FFS := 65 mi/h S_{prev} := 64.0 mi/h PHF := .95 fp := 1

L_B := 3000 ft L_{seg} := 3000 ft L_{prev} := 500 ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$ $L_{midpnts} = 1750$ ft Distance from midpoints of upstream and subject segments

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

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

$$E\_T(Terrain) := \begin{cases} out \leftarrow 1.5 & \text{if } Terrain = 1 \\ out \leftarrow 2.5 & \text{if } Terrain = 2 \\ out \leftarrow 4.5 & \text{if } Terrain = 3 \end{cases}$$

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 2956.736$$

$$OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 483.737$$

$$OnRampVolAdj := \frac{OnRampVol}{PHF \cdot f\_HV\_RF \cdot fp} = 744.211$$

**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*

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

$$f\_HV = 0.986$$

B. Volumes for Weaving Segments

$v\_RR := .05 \cdot OnRampVolAdj = 37.211$ veh/h ** Freeplan assumes the v_RR is 5% of the total On-Ramp volume.*

$v\_FR := OffRampVolAdj - v\_RR = 446.526$ veh/h

$v\_RF := .95 \cdot OnRampVolAdj = 707$ veh/h

$v\_FF := SegInputVolAdj - v\_FR = 2510.21$ veh/h

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 3.701 \times 10^{3}$ veh/h

C. Weaving Demand Flow Rate

$$WeavingDemand(N\_WL) := \begin{vmatrix} out \leftarrow v\_RF + v\_FR & \text{if } N\_WL \neq 0 \\ out \leftarrow v\_RR & \text{if } N\_WL = 0 \end{vmatrix}$$

$WeavingFlowRate := WeavingDemand(N\_WL)$

$WeavingFlowRate = 1154$ pc/h

D. Non-Weaving Demand Flow Rate

$$NonWeavingDemand(N\_WL) := \begin{vmatrix} out \leftarrow v\_FF + v\_RR & \text{if } N\_WL \neq 0 \\ out \leftarrow v\_FF + v\_FR + v\_RF & \text{if } N\_WL = 0 \end{vmatrix}$$

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$NonWeavingFlowRate = 2547$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$TotalFlowRate = 3701$ pc/h

F. Volume Ratio

$$VR := \frac{WeavingFlowRate}{TotalFlowRate}$$

$VR = 0.312$

Step 3. Determine the Maximum Weaving Length

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

$\text{MaximumLength} = 5710$ ft $\quad Ls := L_B \cdot .77 = 2310$

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

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

$C\_IWL = 2090$ pc/h/ln — C_IWL is the capacity per lane under equivalent ideal conditions

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

$Cw1 = 8243$ veh/h — Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

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

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.

$C\_IW := C\_IW(N\_WL) \qquad C\_IW = 7700$ pc/h — C_IW is the capacity of the weaving segment under ideal conditions

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

$Cw2 = 7593$ veh/h — Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

$$\text{WeavingCapacity} := \text{if}\left(Cw1 > Cw2, Cw2, Cw1\right)$$

$\text{WeavingCapacity} = 7593$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$\text{VolumeToCapacity} = 0.481$

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

Step 5. Determine Configuration Characteristics

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

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

$LC\_MIN = 1154$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

$$LaneChangingWeaving := LC\_W(Ls)$$

$LaneChangingWeaving = 1615$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

$$I\_NW := \frac{Ls \cdot Int\_Density \cdot NonWeavingFlowRate}{10000}$$ $I\_NW = 512$ Non Weaving Vehicle Index

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

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

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

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

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

$LaneChangingNonWeaving = 1006$ lc/h

C. Total Lane-Changing Rate

$$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$$

$TotalLaneChanging = 2622$ lc/h

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

A. Average Speed of Weaving Vehicles

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

$$WeavingIntensityFactor = 0.25$$

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

$$AverageWeavingSpeed = 55.01 \quad \text{mi/h}$$

B. Average Speed of Non-Weaving Vehicles

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

$$AverageNonWeavingSpeed = 52.25 \quad \text{mi/h}$$

C. Average Speed of All Vehicles

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

$$AverageSpeed = 53.08 \quad \text{mi/h}$$

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 64.9 \quad \text{mi/h}$$

$$S := \begin{cases} AverageSpeed & \text{if } AverageSpeed \le S_{max} \\ S_{max} & \text{if } AverageSpeed > S_{max} \end{cases} \qquad S = 53.1 \quad \text{mi/h}$$

Step 8. Determine the Level of Service

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

Density = 17.4 pc/mi/ln

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

LOS(Density) = "B"

Step 9. Determine the Input Vol and %HV for the Next Downstream Segment

$$\text{FwyVolNew} := \text{SegInputVol} + (\text{OnRampVol} - \text{v\_RR}) - (\text{OffRampVol} - \text{v\_RR}) = 2981$$

$$\%\text{Trucks}_{\text{FNew}} := \frac{\text{SegInputVol} \cdot \text{SegInput\%HV} + (\text{OnRampVol} - \text{v\_RR}) \cdot \text{OnRamp\%HV} - (\text{OffRampVol} - \text{v\_RR}) \cdot \text{OffRamp\%HV}}{\text{FwyVolNew}}$$

$\%\text{Trucks}_{\text{FNew}} = 5.055$

**FwyVolNew and %Trucks$_{FNew}$ are the input values for FwyVol and %Trucks$_F$ for the next downstream segment if there is one. If the next segment is a weave, then %Trucks$_{FNew}$ is the input value for SegInput%HV and FwyVolNew is the input value for SegInputVol.*

On-Ramp Methodology

Step 1. Data Inputs and Volume Adjusments

**FwyVolNew and %Trucks$_{FNew}$ from the previous upstream segment are the input values for FwyVol and %Trucks$_F$ (if there is a previous upstream segment).*

A. Inputs

$FwyVol := 2981$ veh/h $RampVol := 455$ veh/h

$\%Trucks_F := 5.055$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 64.3$ mi/h Average speed on immediate upstream segment

$NumLanes := 3$ Number of mainline freeway lanes $NRamp := 1$ Number of lanes on ramp roadway

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

$L_{seg} := 1500$ ft $L_{prev} := 500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1000 \text{ ft}$$

Distance from midpoints of upstream and subject segments

$L_A := 1000$ ft Total length of Acceleration Lane

$S_{FR} := 40$ mi/h Freeflow speed of the ramp at the junction point

$AdjUp := 2$ $AdjDn := 2$ 0 = none, 1 = on-ramp, 2 = off-ramp for Adjacent Upstream/Downstream Ramps

$L_{up} := 500$ ft $L_{down} := 8280$ ft

$VolumeUp := 455$ veh/h Volume on adjacent upstream ramp

$VolumeDown := 455$ veh/h Volume on adjacent downstream ramp

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

$$E_T(Terrain) := \begin{cases} out \leftarrow 1.5 & \text{if } Terrain = 1 \\ out \leftarrow 2.5 & \text{if } Terrain = 2 \\ out \leftarrow 4.5 & \text{if } Terrain = 3 \end{cases} \qquad E_R(Terrain) := \begin{cases} out \leftarrow 1.2 & \text{if } Terrain = 1 \\ out \leftarrow 2.0 & \text{if } Terrain = 2 \\ out \leftarrow 4.0 & \text{if } Terrain = 3 \end{cases}$$

$E_T(Terrain) = 1.5$ $E_R(Terrain) = 1.2$

$E_T := E_T(Terrain)$ $E_T = 1.5$ $E_R := E_R(Terrain)$ $E_R = 1.2$

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} = 0.975 \qquad f\_HV_F = 0.975$$

$$f\_HV_R := \frac{100}{100 + \%Trucks_R(E_T - 1) + \%RV_R(E_R - 1)} \qquad f\_HV_R = 0.99$$

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3217 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 484 \text{ pc/h}$$

$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p}$ $V_u = 484$ pc/h $V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p}$ $V_d = 484$ pc/h

Step 2. Determine the Approaching Flow Rate in Lanes 1 and 2

A. Equilibrium Seperation Distance for Adjacent Off-Ramp on a Six Lane Freeway

$L_{EQup} := 0.214(V_f + V_r) + 0.444 \cdot L_A + 52.32 \cdot S_{FR} - 2403$ $L_{EQup} = 926$ ft

$L_{EQdown} := \frac{V_d}{0.1096 + 0.000107 \cdot L_A}$ $L_{EQdown} = 2233$ ft

B. Estimating Proportion of Freeway Vehicles Remaining in lanes 1 and 2

$Eqn1 := 0.5775 + 0.000028 \cdot L_A$ $Eqn1 = 0.606$

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $Eqn2 = 0.579$

$Eqn3 := 0.5487 + 0.2628 \cdot \frac{V_d}{L_{down}}$ $Eqn3 = 0.564$

$P_{FM}(Numlanes) :=$

- $out \leftarrow 1.00$ if $NumLanes = 2$
- $out \leftarrow Eqn1$ if $AdjUp \neq 2 \wedge AdjDn \neq 2 \wedge NumLanes = 3$
- $out \leftarrow Eqn3$ if $AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow Eqn2$ if $AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 1 \wedge AdjDn = 1 \wedge NumLanes = 3$
- $out \leftarrow Eqn3$ if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow Eqn2$ if $AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3$
- $out \leftarrow max(Eqn1, Eqn2)$ if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow max(Eqn3, Eqn2)$ if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow Eqn1$ if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow max(Eqn1, Eqn3)$ if $AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3$
- $out \leftarrow 0.2178 - 0.0000125 \cdot V_r + -0.01115 \cdot \frac{L_A}{S_{FR}}$ if $\left(\frac{V_f}{S_{FR}} \leq 72\right) \wedge (NumLanes = 4)$
- $out \leftarrow 0.2178 - 0.0000125 \cdot V_r$ if $\left(\frac{V_f}{S_{FR}} > 72\right) \wedge (NumLanes = 4)$

$P_{FM} := P_{FM}(NumLanes)$ $P_{FM} = 0.606$

C. Estimating Flow in Lanes 1 and 2

$V_{12} := V_f \cdot P_{FM}$ $V_{12} = 1948$ pc/h

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $V_3 = 1269$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 635$ pc/h

$$
V12a(NumLanes) := \begin{array}{|l}
out \leftarrow V_{12} \ \text{ if } \ NumLanes = 2 \\
out \leftarrow V_f - 2700 \ \text{ if } \ V_3 > 2700 \wedge V_3 \le 1.5 \cdot \frac{V_{12}}{2} \vee NumLanes = 3 \\
out \leftarrow \frac{V_f}{1.75} \ \text{ if } \ V_3 \le 2700 \wedge V_3 > 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 3 \\
out \leftarrow \max\left(V_f - 2700, \frac{V_f}{1.75}\right) \ \text{ if } \ V_3 > 2700 \wedge V_3 > 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 3 \\
out \leftarrow V_{12} \ \text{ if } \ V_3 \le 2700 \wedge V_3 \le 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 3 \\
out \leftarrow V_f - 5400 \ \text{ if } \ V_{av34} > 2700 \wedge V_{av34} \le 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 4 \\
out \leftarrow \frac{V_f}{2.50} \ \text{ if } \ V_{av34} \le 2700 \wedge V_{av34} > 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 4 \\
out \leftarrow \max\left(V_f - 5400, \frac{V_f}{2.50}\right) \ \text{ if } \ V_{av34} > 2700 \wedge V_{av34} > 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 4 \\
out \leftarrow V_{12} \ \text{ if } \ V_{av34} \le 2700 \wedge V_{av34} \le 1.5 \cdot \frac{V_{12}}{2} \wedge NumLanes = 4
\end{array}
$$

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(NumLanes)$ $V_{12} = 1948$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

$V_{R12} := V_{12} + V_r$ $V_{R12} = 2432$ pc/h Flow entering the ramp influence area

$$\text{CapUpFreewaySegment}(\text{NumLanes}, \text{FFS}) := \left| \begin{array}{ll} \text{out} \leftarrow 4800 & \text{if } \text{FFS} \geq 70 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4700 & \text{if } \text{FFS} = 65 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4600 & \text{if } \text{FFS} = 60 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 4600 & \text{if } \text{FFS} = 55 \wedge \text{NumLanes} = 2 \\ \text{out} \leftarrow 7200 & \text{if } \text{FFS} = 70 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 7050 & \text{if } \text{FFS} = 65 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 6900 & \text{if } \text{FFS} = 60 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 6750 & \text{if } \text{FFS} = 55 \wedge \text{NumLanes} = 3 \\ \text{out} \leftarrow 9600 & \text{if } \text{FFS} = 70 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9400 & \text{if } \text{FFS} = 65 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9200 & \text{if } \text{FFS} = 60 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 9000 & \text{if } \text{FFS} = 55 \wedge \text{NumLanes} = 4 \\ \text{out} \leftarrow 2400 \cdot \text{NumLanes} & \text{if } \text{FFS} = 70 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2350 \cdot \text{NumLanes} & \text{if } \text{FFS} = 65 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2300 \cdot \text{NumLanes} & \text{if } \text{FFS} = 60 \wedge \text{NumLanes} > 4 \\ \text{out} \leftarrow 2250 \cdot \text{NumLanes} & \text{if } \text{FFS} = 55 \wedge \text{NumLanes} > 4 \end{array} \right.$$

$\text{CapUpFreewaySegment}(\text{NumLanes}, \text{FFS}) = 7050$ Capacity of Ramp Freeway Junction

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

$$\text{CapacityRampRoadway} := \left| \begin{array}{ll} \text{out} \leftarrow 2200 & \text{if } (\text{NRamp} = 1) \wedge (S_{FR} > 50) \\ \text{out} \leftarrow 2100 & \text{if } (\text{NRamp} = 1) \wedge (40 < S_{FR} \leq 50) \\ \text{out} \leftarrow 2000 & \text{if } (\text{NRamp} = 1) \wedge (30 < S_{FR} \leq 40) \\ \text{out} \leftarrow 1900 & \text{if } (\text{NRamp} = 1) \wedge (20 \leq S_{FR} \leq 30) \\ \text{out} \leftarrow 1800 & \text{if } (\text{NRamp} = 1) \wedge (20 > S_{FR}) \\ \text{out} \leftarrow 4400 & \text{if } (\text{NRamp} = 2) \wedge (S_{FR} > 50) \\ \text{out} \leftarrow 4200 & \text{if } (\text{NRamp} = 2) \wedge (40 < S_{FR} \leq 50) \\ \text{out} \leftarrow 4000 & \text{if } (\text{NRamp} = 2) \wedge (30 < S_{FR} \leq 40) \\ \text{out} \leftarrow 3800 & \text{if } (\text{NRamp} = 2) \wedge (20 \leq S_{FR} \leq 30) \\ \text{out} \leftarrow 3600 & \text{if } (\text{NRamp} = 2) \wedge (20 > S_{FR}) \end{array} \right.$$

$\text{CapacityRampRoadway} = 2000$

$V_{FO} := V_f + V_r$ $V_{FO} = 3701$ pc/h Volume immediatley downstream of on-ramp influence area

Ramp Freeway Junction Checkpoint

Volume immediatley downstream of on-ramp influence area is chekced against freeway capacity. Failure of ramp freeway junction checkpoint (i.e. demand exceeds capacity) results in LOS F

Ramp Roadway Capacity Checkpoint

Capacity or ramp roadway should always be checked against the demand flow rate on the ramp. It is rarely a problem for the on-ramp

Maximum Desirable Flow Entering Ramp Influence Area Checkpoint

While the V_{R12} values is checked against the maximum desirable, failure does not result in assignment of LOS F. Failing this checkpoint generally means that there will be more turbulance in influence area than predicted by this methodology. Thus, predicted densities are most likely lower than those that will exist, and predicted speeds are most likely to be predicted as higher than those that will actually occur.

Step 4. Determine Speeds in the Vicinity of Ramp-Freeway Junction

A. Average Speed in the Ramp Influence Area

$$S_R := FFS - (FFS - 42) \cdot \left[0.321 + 0.0039 \exp\left(\frac{V_{R12}}{1000}\right) - 0.002 \cdot \left(L_A \frac{S_{FR}}{1000}\right)\right] \qquad S_R = 58.44 \quad \text{mi/h}$$

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases} \qquad V_{OA} := \frac{V_f - V_{12}}{No} \qquad V_{OA} = 1269$$

$$S_O(V_{OA}) := \begin{cases} out \leftarrow FFS & \text{if } V_{OA} < 500 \\ out \leftarrow FFS - 0.0036 \cdot (V_{OA} - 500) & \text{if } 500 \le V_{OA} \le 2300 \\ out \leftarrow FFS - 6.53 - 0.006 \cdot (V_{OA} - 2300) & \text{if } V_{OA} > 2300 \end{cases}$$

$$S_O := S_O(V_{OA}) \qquad S_O = 62.23 \quad \text{mi/h}$$

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA} \cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA} \cdot No}{S_O}\right)} \qquad S_{avg} = 59.68 \quad \text{mi/h}$$

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 64.9 \quad \text{mi/h}$$

$$S := \begin{cases} S_{avg} & \text{if } S_{avg} \le S_{max} \\ S_{max} & \text{if } S_{avg} > S_{max} \end{cases} \qquad S = 59.7 \quad \text{mi/h}$$

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

$$Density_R := 5.475 + 0.00734 \cdot V_r + 0.0078 \cdot V_{12} - 0.00627 \cdot L_A$$

$Density_R = 18.0$ pc/mi/ln

B. Density in Outer Lanes

$$Density_O := \frac{V_{OA}}{S_O}$$

$Density_O = 20.4$ pc/mi/ln

C. Density of Entire Cross-Section

$$Density := \begin{array}{|l} out \leftarrow Density_R \quad \text{if} \quad NumLanes \le 2 \\ out \leftarrow \dfrac{\left[Density_R \cdot (2) + Density_O \cdot (NumLanes - 2)\right]}{NumLanes} \quad \text{if} \quad NumLanes > 2 \end{array}$$

$Density = 18.8$ pc/mi/ln

D. Level of Service

$$LOS(Density) := \begin{array}{|l} out \leftarrow \text{"A"} \quad \text{if} \quad 0 \le Density \le 10 \\ out \leftarrow \text{"B"} \quad \text{if} \quad 10 < Density \le 20 \\ out \leftarrow \text{"C"} \quad \text{if} \quad 20 < Density \le 28 \\ out \leftarrow \text{"D"} \quad \text{if} \quad 28 < Density \le 35 \\ out \leftarrow \text{"E"} \quad \text{if} \quad 35 < Density \end{array}$$

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

Step 6. Determine Input Vol and %HV for Next Downstream Segment

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 2830.3$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 445.9$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} + RampVol_{Cars} = 3276.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 150.69$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 9.1$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} + RampVol_{Trucks} = 159.79$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 3436$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 4.6505$$

**FwyVolNew and $\%Trucks_{FNew}$ are the input values for FwyVol and $\%Trucks_F$ for the next downstream segment if there is one. If the next segment is a weave, then $\%Trucks_{FNew}$ is the input value for %Trucks_FF and %Trucks_FR.*

RampOverlap Methodology

The speed and density of the ramp overlap segment are set to the speed and density values of the preceding on-ramp or the following off-ramp that has the higher density. In this case, off-ramp 25 has a higher density than on-ramp 23; thus, the speed and density of the ramp overlap segment are equal to those of the off-ramp.

On-Ramp 23 Speed and Density

$S_{23} := 59.0 \qquad D_{23} := 20.1$

Off-Ramp 25 Speed and Density

$S_{25} := 57.4 \qquad D_{25} := 20.8$

Ramp Overlap 24 Speed and Density

$S_{24} := 57.4 \qquad D_{24} := 20.8$

Overall Facility Density and Speed Calculations

Variable Names

L = Length n = Number of Lanes D = Density S = Speed TT = Travel Time

Notation

i is the segment index and n is the number of segments

$$\text{FacilitySpeed} := \frac{\sum_{i=1}^{n} \text{LSeg}_i}{\sum_{i=1}^{n} \text{TTSeg}_i} \qquad \text{FacilityDensity} := \frac{\sum_{i=1}^{n} \left(\text{nLDSeg}_i\right)}{\sum_{i=1}^{n} \left(\text{nLSeg}_i\right)}$$

FacilitySpeed *= Speed in the entire facility* FacilityDensity *= Density for the entire facility*

1. Basic Segment

Segment Input and Calcs

$S_1 := 65.0 \quad D_1 := 16.8 \quad L_1 := 5280 \quad n_1 := 3 \quad TT_1 := \frac{L_1}{S_1} = 81.231$

$nLD_1 := n_1 \cdot L_1 \cdot D_1 = 266112$

$nL_1 := n_1 \cdot L_1 = 15840$

2. Off-Ramp Segment

Segment Input and Calcs

$S_2 := 59.9 \quad D_2 := 17.9 \quad L_2 := 1500 \quad n_2 := 3 \quad TT_2 := \frac{L_2}{S_2} = 25.042$

$nLD_2 := n_2 \cdot L_2 \cdot D_2 = 80550$

$nL_2 := n_2 \cdot L_2 = 4500$

3. Basic Segment

$S_3 := 64.0 \quad D_3 := 15.4 \quad L_3 := 500 \quad n_3 := 3 \quad TT_3 := \frac{L_3}{S_3} = 7.813$

$nLD_3 := n_3 \cdot L_3 \cdot D_3 = 23100$

$nL_3 := n_3 \cdot L_3 = 1500$

4. Weave Segment

$S_4 := 53.1$ $D_4 := 17.4$ $L_4 := 3000$ $n_4 := 4$ $TT_4 := \frac{L_4}{S_4} = 56.497$

$nLD_4 := n_4 \cdot L_4 \cdot D_4 = 208800$

$nL_4 := n_4 \cdot L_4 = 12000$

5. Basic Segment

$S_5 := 64.3$ $D_5 := 16.7$ $L_5 := 500$ $n_5 := 3$ $TT_5 := \frac{L_5}{S_5} = 7.776$

$nLD_5 := n_5 \cdot L_5 \cdot D_5 = 25050$

$nL_5 := n_5 \cdot L_5 = 1500$

6. On-Ramp Segment

$S_6 := 59.7$ $D_6 := 18.8$ $L_6 := 1500$ $n_6 := 3$ $TT_6 := \frac{L_6}{S_6} = 25.126$

$nLD_6 := n_6 \cdot L_6 \cdot D_6 = 84600$

$nL_6 := n_6 \cdot L_6 = 4500$

7. Basic Segment

$S_7 := 65.0$ $D_7 := 19$ $L_7 := 5280$ $n_7 := 3$ $TT_7 := \frac{L_7}{S_7} = 81.231$

$nLD_7 := n_7 \cdot L_7 \cdot D_7 = 300960$

$nL_7 := n_7 \cdot L_7 = 15840$

8. Off-Ramp Segment

$S_8 := 59.6$ $D_8 := 20.2$ $L_8 := 1500$ $n_8 := 3$ $TT_8 := \frac{L_8}{S_8} = 25.168$

$nLD_8 := n_8 \cdot L_8 \cdot D_8 = 90900$

$nL_8 := n_8 \cdot L_8 = 4500$

9. Basic Segment

$S_9 := 64.7$ $D_9 := 16.6$ $L_9 := 2280$ $n_9 := 3$ $TT_9 := \frac{L_9}{S_9} = 35.24$

$nLD_9 := n_9 \cdot L_9 \cdot D_9 = 113544$

$nL_9 := n_9 \cdot L_9 = 6840$

10. Weave Segment

$S_{10} := 51.8$ $D_{10} := 19.1$ $L_{10} := 4000$ $n_{10} := 4$ $TT_{10} := \frac{L_{10}}{S_{10}} = 77.22$

$nLD_{10} := n_{10} \cdot L_{10} \cdot D_{10} = 305600$

$nL_{10} := n_{10} \cdot L_{10} = 16000$

11. Basic Segment

$S_{11} := 64.9$ $D_{11} := 16.5$ $L_{11} := 2280$ $n_{11} := 3$ $TT_{11} := \frac{L_{11}}{S_{11}} = 35.131$

$nLD_{11} := n_{11} \cdot L_{11} \cdot D_{11} = 112860$

$nL_{11} := n_{11} \cdot L_{11} = 6840$

12. On-Ramp Segment

$S_{12} := 59.6$ $D_{12} := 18.8$ $L_{12} := 1500$ $n_{12} := 3$ $TT_{12} := \frac{L_{12}}{S_{12}} = 25.168$

$nLD_{12} := n_{12} \cdot L_{12} \cdot D_{12} = 84600$

$nL_{12} := n_{12} \cdot L_{12} = 4500$

13. Off-Ramp Segment

$S_{13} := 59.3$ $D_{13} := 20.2$ $L_{13} := 1500$ $n_{13} := 3$ $TT_{13} := \frac{L_{13}}{S_{13}} = 25.295$

$nLD_{13} := n_{13} \cdot L_{13} \cdot D_{13} = 90900$

$nL_{13} := n_{13} \cdot L_{13} = 4500$

14. Basic Segment

$S_{14} := 64.4$ $D_{14} := 16.6$ $L_{14} := 1500$ $n_{14} := 3$ $TT_{14} := \frac{L_{14}}{S_{14}} = 23.292$

$nLD_{14} := n_{14} \cdot L_{14} \cdot D_{14} = 74700$

$nL_{14} := n_{14} \cdot L_{14} = 4500$

15. On-Ramp Segment

$S_{15} := 59.5$ $D_{15} := 19.5$ $L_{15} := 1500$ $n_{15} := 3$ $TT_{15} := \frac{L_{15}}{S_{15}} = 25.21$

$nLD_{15} := n_{15} \cdot L_{15} \cdot D_{15} = 87750$

$nL_{15} := n_{15} \cdot L_{15} = 4500$

16. Basic Segment

$S_{16} := 64.3$ $D_{16} := 20.0$ $L_{16} := 1000$ $n_{16} := 3$ $TT_{16} := \frac{L_{16}}{S_{16}} = 15.552$

$nLD_{16} := n_{16} \cdot L_{16} \cdot D_{16} = 60000$

$nL_{16} := n_{16} \cdot L_{16} = 3000$

17. Off-Ramp Segment

$S_{17} := 58.7$ $D_{17} := 21.1$ $L_{17} := 1500$ $n_{17} := 3$ $TT_{17} := \frac{L_{17}}{S_{17}} = 25.554$

$nLD_{17} := n_{17} \cdot L_{17} \cdot D_{17} = 94950$

$nL_{17} := n_{17} \cdot L_{17} = 4500$

18. Basic Segment

$S_{18} := 64.4$ $D_{18} := 16.1$ $L_{18} := 1500$ $n_{18} := 3$ $TT_{18} := \frac{L_{18}}{S_{18}} = 23.292$

$nLD_{18} := n_{18} \cdot L_{18} \cdot D_{18} = 72450$

$nL_{18} := n_{18} \cdot L_{18} = 4500$

19. WeaveSegment

$S_{19} := 55.0$ $D_{19} := 16.3$ $L_{19} := 1500$ $n_{19} := 4$ $TT_{19} := \frac{L_{19}}{S_{19}} = 27.273$

$nLD_{19} := n_{19} \cdot L_{19} \cdot D_{19} = 97800$

$nL_{19} := n_{19} \cdot L_{19} = 6000$

20. Basic Segment

$S_{20} := 65.0$ $D_{20} := 16.8$ $L_{20} := 5280$ $n_{20} := 3$ $TT_{20} := \frac{L_{20}}{S_{20}} = 81.231$

$nLD_{20} := n_{20} \cdot L_{20} \cdot D_{20} = 266112$

$nL_{20} := n_{20} \cdot L_{20} = 15840$

21. Off-Ramp Segment

$S_{21} := 59.6$ $D_{21} := 17.9$ $L_{21} := 1500$ $n_{21} := 3$ $TT_{21} := \frac{L_{21}}{S_{21}} = 25.168$

$nLD_{21} := n_{21} \cdot L_{21} \cdot D_{21} = 80550$

$nL_{21} := n_{21} \cdot L_{21} = 4500$

22. Basic Segment

$S_{22} := 64.3$ $D_{22} := 14.8$ $L_{22} := 1000$ $n_{22} := 3$ $TT_{22} := \frac{L_{22}}{S_{22}} = 15.552$

$nLD_{22} := n_{22} \cdot L_{22} \cdot D_{22} = 44400$

$nL_{22} := n_{22} \cdot L_{22} = 3000$

23. On-Ramp Segment

$S_{23} := 59.0$ $D_{23} := 20.1$ $L_{23} := 300$ $n_{23} := 3$ $TT_{23} := \frac{L_{23}}{S_{23}} = 5.085$

$nLD_{23} := n_{23} \cdot L_{23} \cdot D_{23} = 18090$

$nL_{23} := n_{23} \cdot L_{23} = 900$

24. Ramp Overlap Segment

$S_{24} := 57.4$ $D_{24} := 20.8$ $L_{24} := 1200$ $n_{24} := 3$ $TT_{24} := \frac{L_{24}}{S_{24}} = 20.906$

$nLD_{24} := n_{24} \cdot L_{24} \cdot D_{24} = 74880$

$nL_{24} := n_{24} \cdot L_{24} = 3600$

25. Off-Ramp Segment

$S_{25} := 57.4$ $D_{25} := 20.8$ $L_{25} := 300$ $n_{25} := 3$ $TT_{25} := \frac{L_{25}}{S_{25}} = 5.226$

$nLD_{25} := n_{25} \cdot L_{25} \cdot D_{25} = 18720$

$nL_{25} := n_{25} \cdot L_{25} = 900$

26. Basic Segment

$S_{26} := 62.4$ $D_{26} := 16.0$ $L_{26} := 1000$ $n_{26} := 3$ $TT_{26} := \frac{L_{26}}{S_{26}} = 16.026$

$nLD_{26} := n_{26} \cdot L_{26} \cdot D_{26} = 48000$

$nL_{26} := n_{26} \cdot L_{26} = 3000$

27. On-Ramp Segment

$S_{27} := 59.5$ $D_{27} := 19.2$ $L_{27} := 1500$ $n_{27} := 3$ $TT_{27} := \frac{L_{27}}{S_{27}} = 25.21$

$nLD_{27} := n_{27} \cdot L_{27} \cdot D_{27} = 86400$

$nL_{27} := n_{27} \cdot L_{27} = 4500$

28. Basic Segment

$S_{28} := 65.0$ $D_{28} := 19.5$ $L_{28} := 5280$ $n_{28} := 3$ $TT_{28} := \frac{L_{28}}{S_{28}} = 81.231$

$nLD_{28} := n_{28} \cdot L_{28} \cdot D_{28} = 308880$

$nL_{28} := n_{28} \cdot L_{28} = 15840$

29. Weave Segment

$S_{29} := 52.9$ $D_{29} := 21$ $L_{29} := 4500$ $n_{29} := 4$ $TT_{29} := \frac{L_{29}}{S_{29}} = 85.066$

$nLD_{29} := n_{29} \cdot L_{29} \cdot D_{29} = 378000$

$nL_{29} := n_{29} \cdot L_{29} = 18000$

30. Basic Segment

$S_{30} := 64.9$ $D_{30} := 20.4$ $L_{30} := 1140$ $n_{30} := 3$ $TT_{30} := \frac{L_{30}}{S_{30}} = 17.565$

$nLD_{30} := n_{30} \cdot L_{30} \cdot D_{30} = 69768$

$nL_{30} := n_{30} \cdot L_{30} = 3420$

31. Weave Segment

$S_{31} := 53.2$ $D_{31} := 20.9$ $L_{31} := 2000$ $n_{31} := 4$ $TT_{31} := \frac{L_{31}}{S_{31}} = 37.594$

$nLD_{31} := n_{31} \cdot L_{31} \cdot D_{31} = 167200$

$nL_{31} := n_{31} \cdot L_{31} = 8000$

32. Basic Segment

$S_{32} := 64.1$ $D_{32} := 20.6$ $L_{32} := 1140$ $n_{32} := 3$ $TT_{32} := \frac{L_{32}}{S_{32}} = 17.785$

$nLD_{32} := n_{32} \cdot L_{32} \cdot D_{32} = 70452$

$nL_{32} := n_{32} \cdot L_{32} = 3420$

33. On-Ramp Segment

$S_{33} := 59$ $D_{33} := 22.8$ $L_{33} := 1500$ $n_{33} := 3$ $TT_{33} := \frac{L_{33}}{S_{33}} = 25.424$

$nLD_{33} := n_{33} \cdot L_{33} \cdot D_{33} = 102600$

$nL_{33} := n_{33} \cdot L_{33} = 4500$

Facility Calcs

$$TotalSegnLD := \sum_{i=1}^{33} nLD_i = 4009278$$

$$TotalSegnL := \left(\sum_{i=1}^{33} nL_i\right) = 215280$$

$$FacilityDensity := \frac{TotalSegnLD}{TotalSegnL} = 18.624$$

$$TotalSegL := \sum_{i=1}^{33} L_i = 66760$$

$$TotalSegTT := \sum_{i=1}^{33} TT_i = 1107.177$$

$$FacilitySpeed := \frac{TotalSegL}{TotalSegTT} = 60.3$$

Appendix G
Calculations Documentation for FREEPLAN
Toll Plaza Analysis Only

FREEPLAN Computational Methodology

Traditional Toll Plaza

For Version 9/30/2012

Dr. Scott Washburn
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Step 1. Input Toll Plaza Data

Number of Lanes

$N_{MB} := 2$

$N_{ACM} := 2$

$N_{ETC} := 1$

Average Service Times

$ST_{MB} := 5.6$ s

$ST_{ACM} := 2.3$ s

Payment Type Composition

$PT_{MB} := 35$ %

$PT_{ACM} := 40$ %

$PT_{ETC} := 25$ %

$FFS_{ETC} := 35$ mi/h

Step 2. Input Freeway Data

Traffic

$FwyVol := 1733$ veh/h

$PHF := 1.000$

$f_p := 0.98$

$\%Trucks_F := 3$

$FFS_{up} := 70.0$ mi/h Average speed on immediate upstream segment

$FFS_{down} := 70.0$ mi/h Average speed on immediate downstream segment

Roadway

$N := 5$ total number of lanes

$L_{up} := 5280$ ft

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

Step 3. Calculate Flow Rate for Each Payment Type

Passenger Car Equivalents

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

$E_T(Terrain) = 1.5$ $E_T := E_T(Terrain)$ $E_T = 1.5$

Heavy Vehicle Adjustment Factor

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1)}$$

$f\_HV_F = 0.985$

Demand Flow Rates

$$V_f := \frac{FwyVol}{PHF \cdot f_p}$$

$V_f = 1768$ veh/h

Toll plaza methodology is based on flow rate units of vehicles, not passenger cars.

$V_{MB} := V_f \cdot \frac{PT_{MB}}{100}$ $V_{MB} = 619$ veh/h

$V_{ACM} := V_f \cdot \frac{PT_{ACM}}{100}$ $V_{ACM} = 707$ veh/h $V_{ETC} := V_f \cdot \frac{PT_{ETC}}{100}$ $V_{ETC} = 442$ veh/h

Step 4. Calculate Capacity

Processing Time

$t_{PullUp} := 3.5 + 0.015 \cdot \%Trucks_F$ $t_{PullUp} = 3.545$ s This assumes a setback distance of 5ft.

$t_{MB} := ST_{MB} + t_{PullUp}$ $t_{MB} = 9.145$ s

$t_{ACM} := ST_{ACM} + t_{PullUp}$ $t_{ACM} = 5.845$ s

Ideal Payment Type Distribution

$$Ideal_{MB} := \frac{\left(\frac{N_{MB}}{t_{MB}}\right)}{\left(\frac{N_{MB}}{t_{MB}}\right) + \left(\frac{N_{ACM}}{t_{ACM}}\right)} \cdot 100$$

$Ideal_{MB} = 38.99$ % $round(Ideal_{MB}) = 39$

$Ideal_{MB} := round(Ideal_{MB})$

$Ideal_{MB} = 39$ %

$$Ideal_{ACM} := \frac{\left(\frac{N_{ACM}}{t_{ACM}}\right)}{\left(\frac{N_{MB}}{t_{MB}}\right) + \left(\frac{N_{ACM}}{t_{ACM}}\right)} \cdot 100$$

$Ideal_{ACM} = 61.01$ % $round(Ideal_{ACM}) = 61$

$Ideal_{ACM} := round(Ideal_{ACM})$

$Ideal_{ACM} = 61$ %

Actual Payment Type Distribution

$Actual_{MB} := \frac{PT_{MB}}{PT_{MB} + PT_{ACM}} \cdot 100$ $Actual_{MB} = 46.67$ %

$round(Actual_{MB}) = 47$ $Actual_{MB} := round(Actual_{MB})$ $Actual_{MB} = 47$ %

$Actual_{ACM} := \frac{PT_{ACM}}{PT_{MB} + PT_{ACM}} \cdot 100$ $Actual_{ACM} = 53.33$ %

$\text{round}(\text{Actual}_{ACM}) = 53$ $\quad \text{Actual}_{ACM} := \text{round}(\text{Actual}_{ACM})$ $\quad \text{Actual}_{ACM} = 53$ %

Determine Base Capacity

$$\text{BaseCapacity}(\text{FFS}_{ETC}) := \begin{array}{|l} \text{out} \leftarrow 1950 \ \text{ if } \ \text{FFS}_{ETC} < 30 \\ \text{out} \leftarrow 2150 \ \text{ if } \ \text{FFS}_{ETC} < 40 \\ \text{out} \leftarrow 2200 \ \text{ otherwise} \end{array}$$

$\text{BaseCapacity}(\text{FFS}_{ETC}) = 2150$ $\quad \text{BaseCapacity} := \text{BaseCapacity}(\text{FFS}_{ETC})$ $\quad \text{BaseCapacity} = 2150$ pc/h/ln

Capacities

$$c_{MB} := \frac{3678.417 \cdot N_{MB}}{t_{MB}} - 2.357 \cdot N_{MB} \cdot \sqrt{\%\text{Trucks}_F}$$ $c_{MB} = 796.3$ veh/h

$$c_{ACM} := \left(\frac{3803.336 \cdot N_{ACM}}{t_{ACM}}\right) \cdot \left[1 - \left(\frac{\text{Ideal}_{ACM} - \text{Actual}_{ACM}}{44.859}\right)\right] - 3.255 \cdot N_{ACM} \cdot \sqrt{\%\text{Trucks}_F}$$ $c_{ACM} = 1058$ veh/h

$c_{nonETC} := c_{MB} + c_{ACM}$ $\quad c_{nonETC} = 1854.3$ veh/h

$c_{ETC} := \min(\text{BaseCapacity} \cdot f\_HV_F \cdot N_{ETC}, V_{ETC})$ $\quad c_{ETC} = 442$ veh/h

$c_{Total} := c_{MB} + c_{ACM} + c_{ETC}$ $\quad c_{Total} = 2296.4$ veh/h

Step 5. Calculate Speed and Density

Demand to Capacity Ratios

$X_{MB} := \frac{V_{MB}}{c_{MB}}$ $\quad X_{MB} = 0.777$ $\quad X_{ACM} := \frac{V_{ACM}}{c_{ACM}}$ $\quad X_{ACM} = 0.669$

ETC-Only Speed and Density

$S_{ETC} := \text{FFS}_{ETC} - 0.00254 \cdot V_{ETC}$ $\quad S_{ETC} = 33.9$ mi/h

$\text{Density}_{ETC} := \frac{V_{ETC}}{S_{ETC}}$ $\quad \text{Density}_{ETC} = 13.0$ veh/h/ln

Regular Lanes Density

$$Density_{nonETC} := e^{(4.1402 \cdot X_{MB})} + e^{(3.3952 \cdot X_{ACM})} - 49.2126 \cdot X_{MB}^{3} + 4.5947 \cdot X_{ACM}$$

$Density_{nonETC} = 14.6$ veh/h/ln

Overall Segment Density

$$Density_{overall} := Density_{nonETC} \cdot \left(\frac{N_{MB} + N_{ACM}}{N}\right) + Density_{ETC} \cdot \left(\frac{N_{ETC}}{N}\right)$$

$Density_{overall} = 14.3$ veh/h/ln

$$DensityPC := \frac{Density_{overall}}{f\_HV_{F}}$$

$DensityPC = 14.5$ pc/h/ln

Regular Lanes Speed

$$S_{nonETC} := \frac{V_{f} \cdot \left(1 - \frac{PT_{ETC}}{100}\right)}{\left(N_{MB} + N_{ACM}\right) \cdot Density_{overall}}$$

$S_{nonETC} = 23.2$ mi/h

$$S_{overall} := \frac{\left(S_{ETC} \cdot FwyVol \cdot \frac{PT_{ETC}}{100}\right) + \left[S_{nonETC} \cdot FwyVol \cdot \left(1 - \frac{PT_{ETC}}{100}\right)\right]}{FwyVol}$$

$S_{overall} = 25.9$ mi/h

Step 6. Calculate Delay

ETC-Only Delay

$$DecelDelay_{ETC} := \left(FFS_{up} - FFS_{ETC}\right) \cdot \frac{1.467}{10}$$

$DecelDelay_{ETC} = 5.135$ s

$$AccelDelay_{ETC} := \left(FFS_{down} - FFS_{ETC}\right) \cdot \frac{1.467}{7}$$

$AccelDelay_{ETC} = 7.335$ s

$$TotDelay_{ETC} := DecelDelay_{ETC} + AccelDelay_{ETC}$$

$TotDelay_{ETC} = 12.5$ s

Non ETC-Only Delay

$$DecelDelay_{nonETC} := \frac{FFS_{up} \cdot \left(\frac{L_{up}}{3600}\right)}{10}$$

$DecelDelay_{nonETC} = 10.267$ s

$$PlazaDelay := 16.3418 + e^{(4.8055 \cdot X_{MB})} + e^{(3.016 \cdot X_{ACM})} - 99.2775 \cdot X_{MB}^{4} - 4.8725 \cdot X_{ACM}$$

$PlazaDelay = 26.254$ s

$TotDelay_{nonETC} := DecelDelay_{nonETC} + PlazaDelay$ $\quad$ $TotDelay_{nonETC} = 36.5$ s

Overall Toll Plaza

$$Delay_{overall} := TotDelay_{nonETC} \cdot \left(\frac{V_{MB} + V_{ACM}}{V_f} \right) + TotDelay_{ETC} \cdot \left(\frac{V_{ETC}}{V_f} \right)$$ $\quad$ $Delay_{overall} = 30.5$ s

Step 7. Determine Level of Service

ETC-Only Lanes LOS

$$LOS(TotDelay_{ETC}) := \begin{array}{|l} out \leftarrow \text{"F"} \quad \text{if } TotDelay_{ETC} > 18 \\ out \leftarrow \text{"E"} \quad \text{if } 18 \ge TotDelay_{ETC} > 16 \\ out \leftarrow \text{"D"} \quad \text{if } 16 \ge TotDelay_{ETC} > 14 \\ out \leftarrow \text{"C"} \quad \text{if } 14 \ge TotDelay_{ETC} > 12 \\ out \leftarrow \text{"B"} \quad \text{if } 12 \ge TotDelay_{ETC} > 10 \\ out \leftarrow \text{"A"} \quad \text{if } 10 \ge TotDelay_{ETC} \\ out \end{array}$$

$LOS(TotDelay_{ETC}) = \text{"C"}$

Non ETC-Only Lanes LOS

$$LOS(TotDelay_{nonETC}) := \begin{array}{|l} out \leftarrow \text{"F"} \quad \text{if } TotDelay_{nonETC} > 60 \\ out \leftarrow \text{"E"} \quad \text{if } 60 \ge TotDelay_{nonETC} > 50 \\ out \leftarrow \text{"D"} \quad \text{if } 50 \ge TotDelay_{nonETC} > 42 \\ out \leftarrow \text{"C"} \quad \text{if } 42 \ge TotDelay_{nonETC} > 36 \\ out \leftarrow \text{"B"} \quad \text{if } 36 \ge TotDelay_{nonETC} > 32 \\ out \leftarrow \text{"A"} \quad \text{if } 32 \ge TotDelay_{nonETC} \\ out \end{array}$$

$LOS(TotDelay_{nonETC}) = \text{"C"}$

Segment LOS

$$LOS(DensityPC) := \begin{array}{|l} out \leftarrow "F" \quad \text{if } Density_{overall} > 45 \\ out \leftarrow "E" \quad \text{if } 45 \ge Density_{overall} > 35 \\ out \leftarrow "D" \quad \text{if } 35 \ge Density_{overall} > 26 \\ out \leftarrow "C" \quad \text{if } 26 \ge Density_{overall} > 18 \\ out \leftarrow "B" \quad \text{if } 18 \ge Density_{overall} > 11 \\ out \leftarrow "A" \quad \text{if } 11 \ge Density_{overall} \\ out \end{array}$$

$$LOS\left(Density_{overall}\right) = "B"$$

FREEPLAN Computational Methodology

ORT Toll Plaza

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For Version 9/30/2012

Open road tolling segments are analyzed with the basic freeway segment methodology.