HIGHPLAN Computational Methodology

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Two-Lane Facility Analysis, Example 2

Inputs and Initial Computations.

1. Input Roadway and Traffic Data.

Roadway Data

$AnalysisType := 0$ 0 = segment, 1 = facility

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

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

$\%NPZ := 50$

$PostedSpeed := 55$

$FFS := PostedSpeed + 5$

Peak Direction is EB

$L_{Seg1} := 3$ mi $\quad L_{Seg2} := 4$ mi $\quad L_{Seg3} := 3 \quad L_{Seg4} := 4$

$L_T := L_{Seg1} + L_{Seg2} + L_{Seg3} + L_{Seg4} \quad L_T = 14$

Traffic Data

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

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

$LocalAdjustmentFactor := 1.0 \quad LAF := LocalAdjustmentFactor$

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

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

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

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

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

Length of basic two-lane segment upstream of first signal (L_{11})

$$L_{eff\_up1} := 43.2463 + 4.2688\cdot\left(\frac{v_p}{100}\right)^2 + 5.2178\cdot C - 57.3041\cdot\left(\frac{v_p}{100}\right)\cdot\frac{\%LT}{100} - 5.2444\cdot C\cdot g\_C$$

$L_{eff\_up1} = 369.77$ (ft) $L_{eff\_up1} := \frac{L_{eff\_up1}}{5280}$ $L_{eff\_up1} = 0.07$ (mi)

$L_{11} := L_{Seg1} - L_{eff\_up1}$ $L_{11} = 2.930$ (mi)

Length of signal 1 influence area (L_{12})

$L_{A1} := \frac{0.1655\cdot FFS^{2.0917}}{5280}$ $L_{A1} = 0.164$ (mi) Acceleration distance from stop at signal

$L_{12} := L_{eff\_up1} + L_{A1}$ $L_{12} = 0.234$ (mi)

Length of transition two-lane highway downstream of signal 1 influence area (L_{13})

$L_{eff\_down1} := 2.218584 - 0.122942\cdot\left(\frac{v_p}{100}\right)$ $L_{eff\_down1} = 1.442$ (mi)

$L_{13} := L_{eff\_down1} - L_{A1}$ $L_{13} = 1.278$ (mi)

Length of influence area upstream of signal 2

$$L_{eff\_up2} := 43.2463 + 4.2688\cdot\left(\frac{v_p}{100}\right)^2 + 5.2178\cdot C - 57.3041\cdot\left(\frac{v_p}{100}\right)\cdot\frac{\%LT}{100} - 5.2444\cdot C\cdot g\_C$$

$L_{eff\_up2} = 369.77$ (ft) $L_{eff\_up2} := \frac{L_{eff\_up2}}{5280}$ $L_{eff\_up2} = 0.07$ (mi)

Length of basic two-lane segment downstream of signal 1 (L_{14})

$$L_{14} := (L_{Seg1} + L_{Seg2}) - (L_{11} + L_{12} + L_{13} + L_{eff\_up2}) \qquad L_{14} = 2.488 \quad (mi)$$

Length of signal 2 influence area (L_{22})

$$L_{A2} := \frac{0.1655 \cdot FFS^{2.0917}}{5280} \qquad L_{A2} = 0.164 \quad (mi)$$ Acceleration distance from stop at signal

$$L_{22} := L_{eff\_up2} + L_{A2} \qquad L_{22} = 0.234 \quad (mi)$$

Length of transition two-lane highway downstream of signal 2 influence area (L_{23})

$$L_{eff\_down2} := 2.218584 - 0.122942 \cdot \left(\frac{v_p}{100}\right) \qquad L_{eff\_down2} = 1.442 \quad (mi)$$

$$L_{23} := L_{eff\_down2} - L_{A2} \qquad L_{23} = 1.278 \quad (mi)$$

Length of influence area upstream of signal 3

$$L_{eff\_up3} := 43.2463 + 4.2688 \cdot \left(\frac{v_p}{100}\right)^2 + 5.2178 \cdot C - 57.3041 \cdot \left(\frac{v_p}{100}\right) \cdot \frac{\%LT}{100} - 5.2444 \cdot C \cdot g\_C$$

$$L_{eff\_up3} = 369.77 \quad (ft) \qquad L_{eff\_up3} := \frac{L_{eff\_up3}}{5280} \qquad L_{eff\_up3} = 0.07 \quad (mi)$$

Length of basic two-lane segment downstream of signal 2 (L_{31})

$$L_{31} := (L_{Seg1} + L_{Seg2} + L_{Seg3}) - (L_{11} + L_{12} + L_{13} + L_{14} + L_{22} + L_{23} + L_{eff\_up3})$$

$$L_{31} = 1.488 \quad (mi)$$

Length of signal 3 influence area (L_{32})

$$L_{A3} := \frac{0.1655 \cdot FFS^{2.0917}}{5280} \qquad L_{A3} = 0.164 \quad (mi)$$ Acceleration distance from stop at signal

$$L_{32} := L_{eff\_up3} + L_{A3} \qquad L_{32} = 0.234 \quad (mi)$$

Length of transition two-lane highway downstream of signal 3 influence area (L_{33})

$L_{eff\_down3} := 2.218584 - 0.122942 \cdot \left(\frac{v_p}{100}\right)$ $\quad$ $L_{eff\_down3} = 1.442$ (mi)

$L_{33} := L_{eff\_down3} - L_{A3}$ $\quad$ $L_{33} = 1.278$ (mi)

Length of basic two-lane segment downstream of signal 3 (L_{34})

$L_{34} := (L_T) - (L_{11} + L_{12} + L_{13} + L_{14} + L_{22} + L_{23} + L_{31} + L_{32} + L_{33})$

$L_{34} = 2.558$ (mi)

3. Estimate the free-flow speed

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

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

$ATS_{11} := 49.63$ mi/h $\quad$ See ATS calculations section below

$ATS_{14} := 49.63$ mi/h

$ATS_{31} := 49.63$

$ATS_{34} := 49.63$

5. Calculate control delay at the signalized intersection influence area

$ControlDelay1 := 12.62$ sec/veh $\quad$ See signal delay calculations section below

$ControlDelay2 := 12.62$

$ControlDelay3 := 12.62$

6. Determine average travel speed on the affected downstream segment

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

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

$f_{ATS} := \mathrm{InterpolateFlow}(600, 660, 1.800, 440, 1.320)$ $f_{ATS} = 1.669$ need to adjust for PHF

$ATS_{13} := ATS_{14} - f_{ATS}$ $ATS_{13} = 47.96$ mi/h

$ATS_{23} := ATS_{31} - f_{ATS}$

$ATS_{33} := ATS_{34} - f_{ATS}$

7. Determine the delay of every segment

<u>Segments 1 and 2, and Signal 1</u>

Segment 1

$L_{11} = 2.93$ $S_{11} := ATS_{11}$ $S_{11} = 49.63$ $FFS = 60$

$D_{11} := \left(\dfrac{L_{11}}{S_{11}} - \dfrac{L_{11}}{FFS}\right)\cdot 3600$ $D_{11} = 36.732$

Signal 1

$L_{12} = 0.234$

$D_{12} := \mathrm{ControlDelay1}$ $D_{12} = 12.62$

Segment 2

$L_{13} = 1.278$ $S_{13} := ATS_{13}$ $S_{13} = 47.961$ $FFS = 60$

$D_{13} := \left(\dfrac{L_{13}}{S_{13}} - \dfrac{L_{13}}{FFS}\right)\cdot 3600$ $D_{13} = 19.246$

$L_{14} = 2.488$ $S_{14} := ATS_{14}$ $S_{14} = 49.63$ $FFS = 60$

$D_{14} := \left(\dfrac{L_{14}}{S_{14}} - \dfrac{L_{14}}{FFS}\right)\cdot 3600$ $D_{14} = 31.19$

<u>Signal 2</u>

$L_{22} = 0.234$

$D_{22} := \mathrm{ControlDelay2}$ $D_{22} = 12.62$

$L_{23} = 1.278$ $S_{23} := ATS_{23}$ $S_{23} = 47.961$ $FFS = 60$

$$D_{23} := \left(\frac{L_{23}}{S_{23}} - \frac{L_{23}}{FFS}\right) \cdot 3600 \qquad D_{23} = 19.246$$

Segments 3 and 4, and Signal 3

$L_{31} = 1.488 \qquad S_{31} := ATS_{31} \qquad S_{31} = 49.63$ Segment 3

$$D_{31} := \left(\frac{L_{31}}{S_{31}} - \frac{L_{31}}{FFS}\right) \cdot 3600 \qquad D_{31} = 18.653$$

$L_{32} = 0.234$

Signal 3

$D_{32} := \text{ControlDelay3} \qquad D_{32} = 12.62$

$L_{33} = 1.278 \quad S_{33} := ATS_{33} \quad S_{33} = 47.961 \quad FFS = 60$ Segment 4

$$D_{33} := \left(\frac{L_{33}}{S_{33}} - \frac{L_{33}}{FFS}\right) \cdot 3600 \qquad D_{33} = 19.246$$

$L_{34} = 2.558 \quad S_{34} := ATS_{34} \quad S_{34} = 49.63 \quad FFS = 60$

$$D_{34} := \left(\frac{L_{34}}{S_{34}} - \frac{L_{34}}{FFS}\right) \cdot 3600 \qquad D_{34} = 32.068$$

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

1. The total length of the facility:

$L_t := L_{11} + L_{12} + L_{13} + L_{14} + L_{22} + L_{23} + L_{31} + L_{32} + L_{33} + L_{34} \qquad L_t = 14.0$ mi

2. The total delay of the facility:

$D_T := D_{11} + D_{12} + D_{13} + D_{14} + D_{22} + D_{23} + D_{31} + D_{32} + D_{33} + D_{34} \qquad D_T = 214.24$ sec/veh

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

$T_{tFFS} := \left(\frac{L_t}{FFS}\right) \cdot 3600 \qquad T_{tFFS} = 840$ sec/veh

4. Calculate actual travel speed

$$S_{act} := \frac{L_t}{T_{tFFS} + D_T} \cdot 3600 \qquad S_{act} = 47.8 \qquad \text{mi/h}$$

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

$$PTD := \left(\frac{D_T}{T_{tFFS}}\right) \cdot 100 \qquad PTD = 25.5 \qquad (\%)$$

9. Determine the Level of Service

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

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

Signal Delay Calculations

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

$$E_T := 2.0$$

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1)} \qquad f_{HV} = 0.952$$

$$P_{RT} := \frac{\dfrac{v_{RT}}{PHF}}{v_p - \dfrac{v_{LT}}{PHF}} \qquad P_{RT} = 0.091$$

$$f_{RT} := 1.0 - 0.15 \cdot P_{RT} \qquad f_{RT} = 0.986$$

shared lane equation instead of single lane

$$BaseSatFlowRate := 1900$$

$$AdjSatFlowRate := BaseSatFlowRate \cdot f_{HV} \cdot f_{RT} \qquad AdjSatFlowRate = 1784.8$$

$$c := AdjSatFlowRate \cdot g\_C \qquad c = 1070.9$$

$$ThruMvmtFlowRate_1 := v_p \cdot \left[1 - \left(\frac{\%LT}{100}\right)\right] \qquad ThruMvmtFlowRate_1 = 578.9$$

$$vc_1 := \frac{ThruMvmtFlowRate_1}{c \cdot 1} \qquad vc_1 = 0.541$$

b. Calculate uniform delay (d_1)

$$d_{1\_1} := \frac{0.5 \cdot C \cdot (1 - g\_C)^2}{1 - \left(vc_1 \cdot g\_C\right)} \qquad d_{1\_1} = 10.7$$

Equation 15-2
HCM 2000

c. Calculate incremetal delay (d_2)

Determine k, signal controller mode delay adjustment factor

$k := 0.5$ pretimed mode

Determine I, the incremental delay adjustment factor

$I := 1.0$ random arrivals

Calculate incremetal delay (d_2)

Definition:

$T := 0.25$ (default)

Calculation:

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

Equation 15-3
HCM 2000

$$d_{2\_1} = 2.0$$

d. Calculate the total delay

Calculations:

$PF := 1$

$TotDelay_1 := d_{1\_1} \cdot PF + d_{2\_1}$

Equation 15-1
HCM 2000

$TotDelay_1 = 12.62$

ATS Calculations

2. Calculate DDHV (Design Directional Hour Volume)

Calculation:

$DDHV := v_p \cdot PHF$ $\qquad DDHV = 600$

3. 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 median present, MadAdj = 0 otherwise.

Calculations:

Left Turn Lane:

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

$LTadj(LeftTurnLane) = 0$ $\qquad LTadj := LTadj(LeftTurnLane)$ $\qquad LTadj = 0$

Median:

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

$MedAdj(Median) = 0$ $\qquad MedAdj := MedAdj(Median)$ $\qquad MedAdj = 0$

Final Adjustment Value for Left Turn Lane and Median:

$AdjMedLTL := 1 + LTadj + MedAdj$

$AdjMedLTL = 1$

4. Determine Facility Adjustment Factor (FacAdj).

FacAdj = 1.0 for Analysis Type = Segment

FacAdj = 0.9 for Analysis Type = Facility

Calculation:

$$FacAdj(AnalysisType) := \left| \begin{array}{l} out \leftarrow 1.0 \ \text{ if } \ AnalysisType = 0 \\ out \leftarrow 0.9 \ \text{ if } \ AnalysisType = 1 \\ out \end{array} \right.$$

$FacAdj(AnalysisType) = 1$ $\qquad$ $FacAdj := FacAdj(AnalysisType)$ $\qquad$ $FacAdj = 1$

5. Calculate Adjusted Volume (AdjVol).

Calculation:

$$AdjVol := \frac{DDHV}{PHF \cdot LAF \cdot AdjMedLTL \cdot FacAdj}$$

$AdjVol = 631.6$ veh/h $\qquad$ $V := AdjVol$ $\qquad$ $V = 631.6$ veh/h

6. Determine E_T (Truck passenger car equivalency factor).

Calculation:

$$
\mathrm{PCEs}(\mathrm{Terrain}, V) := \left|
\begin{array}{l}
\text{if Terrain} = 1 \\
\quad \left|
\begin{array}{l}
E_T \leftarrow 1.7 \ \text{ if } 0 \le V \le 300 \\
E_T \leftarrow 1.2 \ \text{ if } 300 < V \le 600 \\
E_T \leftarrow 1.1 \ \text{ if } V > 600 \\
E_R \leftarrow 1.0 \\
\text{out} \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\
\text{out}
\end{array}
\right. \\
\text{if Terrain} = 2 \\
\quad \left|
\begin{array}{l}
E_T \leftarrow 2.5 \ \text{ if } 0 \le V \le 300 \\
E_T \leftarrow 1.9 \ \text{ if } 300 < V \le 600 \\
E_T \leftarrow 1.5 \ \text{ if } V > 600 \\
E_R \leftarrow 1.1 \\
\text{out} \leftarrow \begin{pmatrix} E_T \\ E_R \end{pmatrix} \\
\text{out}
\end{array}
\right. \\
\text{out}
\end{array}
\right.
$$

From Exhibit 20-9
HCM 2000

$$\mathrm{PCEs}(\mathrm{Terrain}, V) = \begin{pmatrix} 1.1 \\ 1.0 \end{pmatrix}$$

$E_T := \mathrm{PCEs}(\mathrm{Terrain}, V)_1$ $\quad E_T = 1.1$

$E_R := \mathrm{PCEs}(\mathrm{Terrain}, V)_2$ $\quad E_R = 1.0$

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

Calculation:

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

From Equation 20-4
HCM 2000

$f_{HV} = 0.995$

8. Determine grade adjustment factor (f_G).

Calculation:

$$
f_G(\text{Terrain}, V) := \begin{array}{|l} \text{if Terrain} = 1 \\ \quad \begin{array}{|l} f_G \leftarrow 1.0 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \\ \text{if Terrain} = 2 \\ \quad \begin{array}{|l} f_G \leftarrow 0.71 \;\; \text{if } 0 \le V \le 300 \\ f_G \leftarrow 0.93 \;\; \text{if } 300 < V \le 600 \\ f_G \leftarrow 0.99 \;\; \text{if } V > 600 \\ \text{out} \leftarrow f_G \\ \text{out} \end{array} \\ \text{out} \end{array}
$$

From Exhibit 20-7
HCM 2000

$f_G(\text{Terrain}, V) = 1$ $\quad f_G := f_G(\text{Terrain}, V)$ $\quad f_G = 1$

9. Calculate forward direction volume (v_d).

Calculations:

$$v_d := \frac{V}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-12
HCM 2000

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

$$v_d := \frac{AdjVol}{f_G \cdot f_{HV}}$$

$v_d = 634.7$ pc/h

Check this value against flow range used for Exhbits 20-10 and 20-8, and repeat steps 6 through 9 as necessary.

10. Calculate opposing direction volume (v_o).

Calculations:

$$v_o := \frac{V_o}{PHF \cdot f_G \cdot f_{HV}}$$

From Equation 20-13
HCM 2000

The "equivalent" is performed by the following equation:

$$v_o := \frac{v_d \cdot (1 - D)}{D}$$

$v_o = 423.2$ pc/h

f_G and f_{HV} are not currently accounted for in the determination of v_o as they are in the HCM 2000 methodology. Additionally, the PHF is assumed to be the same in the off-peak direction.

11. Determine adjustment for % no-passing zones in analysis direction (f_{np}) for HCM Equation 20-15.

Look up value from HCM Exhibit 20-19 (linear interpolation if necessary, by both volume and percent no-passing zone).

Input:

$\text{PostedSpeed} = 55$ $\%\text{NPZ} = 50$ $v_o = 423.2$

$\text{FFS} := \text{PostedSpeed} + 5$

$\text{FFS} = 60$

Calculation:

This example calls for interpolation by %NPZ and volume

$$\text{Interp1} := 2.0 + (\%\text{NPZ} - 40) \cdot \left(\frac{2.5 - 2.0}{60 - 40}\right) \qquad \text{Interp1} = 2.25$$

From Exhibit 20-19
HCM 2000

$$\text{Interp2} := 1.3 + (\%\text{NPZ} - 40) \cdot \left(\frac{1.6 - 1.3}{60 - 40}\right) \qquad \text{Interp2} = 1.45$$

$$f_{np} := 2.25 - (v_o - 400) \cdot \left(\frac{\text{Interp1} - \text{Interp2}}{600 - 400}\right)$$

$f_{np} = 2.157$

12. Calculate average travel speed (ATS).

Input:

$FFS_d := FFS$ $\quad FFS_d = 60$ from inputs

$v_d = 634.7$ from step 9

$v_o = 423.2$ from step 10

$f_{np} = 2.16$ from step 11

Calculation:

$$ATS_d := FFS_d - 0.00776 \cdot (v_d + v_o) - f_{np}$$

From Equation 20-5
HCM 2000

$ATS_d = 49.63$ mi/h