

Basic Freeway Segments Worksheet

Number of Lanes Required (N)

Speed-Flow and Density Curves (see Exhibit 23-3 and Equation 23-4)

The functions defined here are only used to plot the Free-Flow Speed and Density curves of Exhibit 23-3. These curves are shown at the end of the worksheet.

Function to evaluate the Average Passenger-Car Speed (SS) for different free-flow speeds. The arguments of the function are the flow rate (vp) and the free-flow speed (ffs). This function uses the equations shown in the notes of Exhibit 23-3.

$$SS(vp, ffs) := \begin{cases} \text{if } ffs = 75 \\ \left[\begin{array}{l} ffs \text{ if } 0 \leq vp \leq (3400 - 30 \cdot ffs) \\ ffs - \left[\left(ffs - \frac{160}{3} \right) \cdot \left(\frac{vp + 30 \cdot ffs - 3400}{30 \cdot ffs - 1000} \right)^{2.6} \right] \end{array} \right] \text{ if } (3400 - 30 \cdot ffs) \leq vp \leq 2400 \\ \text{otherwise} \\ \left[\begin{array}{l} ffs \text{ if } 0 \leq vp \leq (3400 - 30 \cdot ffs) \\ ffs - \left[\frac{1}{9} \cdot (7 \cdot ffs - 340) \cdot \left(\frac{vp + 30 \cdot ffs - 3400}{40 \cdot ffs - 1700} \right)^{2.6} \right] \end{array} \right] \text{ if } (3400 - 30 \cdot ffs) \leq vp \leq (1700 + 10 \cdot ffs) \end{cases}$$

Function to evaluate the Average Passenger-Car Speed (ss) for different densities. The arguments of the function are the flow rate (vp) and the density (DD). This function uses the Equation 23-4.

$$ss(vp, DD) := \frac{vp}{DD}$$

Units definition

Definition of new units. In this case the unit for liters (L) is used, but any other units could be used.

$$\text{veh} := \frac{L}{L} \quad \text{pc} := \frac{L}{L} \quad \text{ln} := \frac{L}{L} \quad \text{I} := \frac{L}{L}$$

General Information

Analyst: Analyst
 Agency or Company: Agency or Company
 Date Performed: Date Performed
 Analysis Time Period: Analysis Time Period

Type of analysis: Design Planning

Site Information

Highway/Direction of Travel: Highway/Direction
 From/To: From/To
 Jurisdiction: Jurisdiction
 Analysis Year: Analysis Year
 Freeway segment area: Rural Urban

Minimum LOS desired: **B**

Flow Inputs

Volume:	$V := 4000 \frac{\text{veh}}{\text{hr}}$	Peak-hour factor:	PHF := 0.85
Annual avg. daily traffic ¹ :	$\text{ADDT} := 0 \frac{\text{veh}}{\text{day}}$	% Trucks and buses:	P _T := 15
Peak-hour proportion of ADDT:	K := 0	% RVs:	P _R := 3
Peak-hour direction proportion:	D := 0	General terrain:	Level
Directional design-hour volume:		Grade:	None
DDHV := $\text{ADDT} \cdot K \cdot D \cdot \frac{\text{day}}{\text{hr}}$	$\text{DDHV} = 0 \frac{\text{veh}}{\text{hr}}$	Length := 0mi	
Driver type:	<input checked="" type="radio"/> Commuter//Weekday	UpDown := 0%	
	<input type="radio"/> Recreational//Weekend		

Note: 1. If ADDT is not provided, v_p is computed using V. Otherwise v_p is computed using DDHV.

Variables used in this section and not defined in HCM

ER23: matrix of E_R values for upgrades between 2% and 3%
ER34: matrix of E_R values for upgrades between 3% and 4%
ER45: matrix of E_R values for upgrades between 4% and 5%
ER5: matrix of E_R values for upgrades greater than 5%
ET23: matrix of E_T values for upgrades between 2% and 3%
ET34: matrix of E_T values for upgrades between 3% and 4%
ET45: matrix of E_T values for upgrades between 4% and 5%
ET46: matrix of E_T values for downgrades greater than 4%
ET56: matrix of E_T values for upgrades between 5% and 6%
ET6: matrix of E_T values for upgrades greater than 6%
Gt: defines the type of terrain of the freeway
Grade: defines whether a specific grade exists or not
Length: length of freeway grade
PRB: vector of percentage of RVs
PT: vector of percentage of trucks of Exhibit 23-11
PTB: vector of percentage of trucks and buses of Exhibit 23-9
UpDown: freeway grade

Passenger-Car equivalents for trucks and buses on upgrades (see Exhibit 23-9)

The E_T matrices are the transpose of Exhibit 23-9. This is done in order to match the data of the matrices with the vector of percentage of trucks and buses (PTB)

$$\text{PTB} := \begin{pmatrix} 2 \\ 4 \\ 5 \\ 6 \\ 8 \\ 10 \\ 15 \\ 20 \\ 25 \end{pmatrix} \quad \text{ET23} := \begin{pmatrix} 1.5 & 1.5 & 1.5 & 2 & 2.5 & 3 \\ 1.5 & 1.5 & 1.5 & 2 & 2.5 & 3 \\ 1.5 & 1.5 & 1.5 & 2 & 2.5 & 2.5 \\ 1.5 & 1.5 & 1.5 & 2 & 2.5 & 2.5 \\ 1.5 & 1.5 & 1.5 & 1.5 & 2 & 2 \\ 1.5 & 1.5 & 1.5 & 1.5 & 2 & 2 \\ 1.5 & 1.5 & 1.5 & 1.5 & 2 & 2 \\ 1.5 & 1.5 & 1.5 & 1.5 & 2 & 2 \\ 1.5 & 1.5 & 1.5 & 1.5 & 2 & 2 \end{pmatrix} \quad \text{ET34} := \begin{pmatrix} 1.5 & 2 & 2.5 & 3 & 3.5 & 4 \\ 1.5 & 2 & 2.5 & 3 & 3.5 & 3.5 \\ 1.5 & 2 & 2 & 2.5 & 3 & 3 \\ 1.5 & 2 & 2 & 2.5 & 3 & 3 \\ 1.5 & 2 & 2 & 2.5 & 3 & 3 \\ 1.5 & 2 & 2 & 2.5 & 3 & 3 \\ 1.5 & 1.5 & 2 & 2 & 2.5 & 2.5 \\ 1.5 & 1.5 & 2 & 2 & 2.5 & 2.5 \\ 1.5 & 1.5 & 2 & 2 & 2.5 & 2.5 \end{pmatrix}$$

$$\text{ET45} := \begin{pmatrix} 1.5 & 3 & 3.5 & 4 & 5 \\ 1.5 & 2.5 & 3 & 3.5 & 4 \\ 1.5 & 2.5 & 3 & 3.5 & 4 \\ 1.5 & 2.5 & 3 & 3.5 & 4 \\ 1.5 & 2 & 2.5 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3 \\ 1.5 & 2 & 2.5 & 3 & 3 \\ 1.5 & 2 & 2.5 & 3 & 3 \end{pmatrix} \quad \text{ET56} := \begin{pmatrix} 2 & 4 & 4.5 & 5 & 5.5 & 6 \\ 2 & 3 & 4 & 4.5 & 5 & 5 \\ 1.5 & 2.5 & 3.5 & 4 & 4.5 & 5 \\ 1.5 & 2.5 & 3 & 3.5 & 4 & 4.5 \\ 1.5 & 2 & 2.5 & 3 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3 & 3.5 \\ 1.5 & 2 & 2.5 & 3 & 3 & 3.5 \end{pmatrix} \quad \text{ET6} := \begin{pmatrix} 4 & 4.5 & 5 & 5.5 & 6 & 7 \\ 3 & 4 & 4.5 & 5 & 5.5 & 6 \\ 2.5 & 3.5 & 4 & 4.5 & 5 & 5.5 \\ 2.5 & 3.5 & 4 & 4.5 & 5 & 5.5 \\ 2.5 & 3.5 & 3.5 & 4 & 4.5 & 5 \\ 2.5 & 3 & 3 & 3.5 & 4 & 4.5 \\ 2 & 2.5 & 2.5 & 3 & 3.5 & 4 \\ 2 & 2.5 & 2.5 & 3 & 3.5 & 4 \\ 2 & 2.5 & 2.5 & 3 & 3.5 & 4 \end{pmatrix}$$

Passenger-Car equivalents for trucks and buses on downgrades (see Exhibit 23-11)

The first two rows of Exhibit 23-11 are not used, because all the values are the same and therefore the E_T value is the same for any % of trucks (see below for calculation of E_T for downgrades).

The E_T matrix is the transpose of Exhibit 23-11. This is done in order to match the data of the matrix with the vector of percentage of trucks (PT).

$$\text{PT} := \begin{pmatrix} 5 \\ 10 \\ 15 \\ 20 \end{pmatrix} \quad \text{ET46} := \begin{pmatrix} 2 & 5.5 & 7.5 \\ 2 & 4 & 6 \\ 2 & 4 & 5.5 \\ 1.5 & 3 & 4.5 \end{pmatrix}$$

Passenger-Car equivalents of Trucks and Buses (see Exhibit 23-8, Exhibit 23-9 and Exhibit 23-11)

If no specific grade exists (Grade = 1), the first row of Exhibit 23-8 is used to define the E_T value. If specific upgrades exists (Grade = 2), the Exhibit 23-9 is used and if specific downgrades exists (Grade = 3), the Exhibit 23-11 is used.

$E_T :=$ if Grade = 1

- 1.5 if Gt = 1
- 2.5 if Gt = 2
- 4.5 if Gt = 3

Gt = 1: Level terrain
 Gt = 2: Rolling terrain
 Gt = 3: Mountainous terrain

if Grade = 2

1.5 if (UpDown < 2%)

if 2% ≤ UpDown ≤ 3%

- linterp(PTB, ET23⁽⁰⁾, P_T) if 0mi ≤ Length ≤ 0.25mi
- linterp(PTB, ET23⁽¹⁾, P_T) if 0.25mi < Length ≤ 0.5mi
- linterp(PTB, ET23⁽²⁾, P_T) if 0.5mi < Length ≤ 0.75mi
- linterp(PTB, ET23⁽³⁾, P_T) if 0.75mi < Length ≤ 1mi
- linterp(PTB, ET23⁽⁴⁾, P_T) if 1mi < Length ≤ 1.5mi
- linterp(PTB, ET23⁽⁵⁾, P_T) if Length > 1.5mi

if 3% < UpDown ≤ 4%

- linterp(PTB, ET34⁽⁰⁾, P_T) if 0mi ≤ Length ≤ 0.25mi
- linterp(PTB, ET34⁽¹⁾, P_T) if 0.25mi < Length ≤ 0.5mi
- linterp(PTB, ET34⁽²⁾, P_T) if 0.5mi < Length ≤ 0.75mi
- linterp(PTB, ET34⁽³⁾, P_T) if 0.75mi < Length ≤ 1mi
- linterp(PTB, ET34⁽⁴⁾, P_T) if 1mi < Length ≤ 1.5mi
- linterp(PTB, ET34⁽⁵⁾, P_T) if Length > 1.5mi

if 4% < UpDown ≤ 5%

- linterp(PTB, ET45⁽⁰⁾, P_T) if 0mi ≤ Length ≤ 0.25mi
- linterp(PTB, ET45⁽¹⁾, P_T) if 0.25mi < Length ≤ 0.5mi
- linterp(PTB, ET45⁽²⁾, P_T) if 0.5mi < Length ≤ 0.75mi
- linterp(PTB, ET45⁽³⁾, P_T) if 0.75mi < Length ≤ 1mi
- linterp(PTB, ET45⁽⁴⁾, P_T) if Length > 1mi

if 5% < UpDown ≤ 6%

- linterp(PTB, ET56⁽⁰⁾, P_T) if 0mi ≤ Length ≤ 0.25mi
- linterp(PTB, ET56⁽¹⁾, P_T) if 0.25mi < Length ≤ 0.3mi
- linterp(PTB, ET56⁽²⁾, P_T) if 0.3mi < Length ≤ 0.5mi
- linterp(PTB, ET56⁽³⁾, P_T) if 0.5mi < Length ≤ 0.75mi
- linterp(PTB, ET56⁽⁴⁾, P_T) if Length > 0.75mi

The value of E_T is calculated linear interpolation of the % t_i and buses (P_T) at the vector l the matrix ET. The grade def which matrix ET must be use the length of the grade define column of that matrix must be in the interpolation

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| | linterp(PTB,ET56<sup>0</sup>,PT) if 0.75mi < Length ≤ 1mi
| | linterp(PTB,ET56<sup>5</sup>,PT) if Length > 1mi
| if UpDown > 6%
| | linterp(PTB,ET6<sup>0</sup>,PT) if 0mi ≤ Length ≤ 0.25mi
| | linterp(PTB,ET6<sup>1</sup>,PT) if 0.25mi < Length ≤ 0.3mi
| | linterp(PTB,ET6<sup>2</sup>,PT) if 0.3mi < Length ≤ 0.5mi
| | linterp(PTB,ET6<sup>3</sup>,PT) if 0.5mi < Length ≤ 0.75mi
| | linterp(PTB,ET6<sup>4</sup>,PT) if 0.75mi < Length ≤ 1mi
| | linterp(PTB,ET6<sup>5</sup>,PT) if Length > 1mi
| if Grade = 3
| | 1.5 if (UpDown < 4%)
| | 1.5 if (4% ≤ UpDown ≤ 5%) ∧ Length ≤ 4mi
| | linterp(PT,ET46<sup>0</sup>,PT) if (4% ≤ UpDown ≤ 5%) ∧ Length > 4mi
| | 1.5 if (5% < UpDown ≤ 6%) ∧ Length ≤ 4mi
| | linterp(PT,ET46<sup>1</sup>,PT) if (5% < UpDown ≤ 6%) ∧ Length > 4mi
| | 1.5 if UpDown > 6% ∧ Length ≤ 4mi
| | linterp(PT,ET46<sup>2</sup>,PT) if UpDown > 6% ∧ Length > 4mi

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The value of E_T is calculated linear interpolation of the % t and buses (P_T) at the vector l the matrix ET46. The downgr the length of the grade define column of that matrix must be in the interpolation

Passenger-Car equivalents for RVs on upgrades (see Exhibit 23-10)

The E_T matrices are the transpose of Exhibit 23-10. This is done in order to match the data of the matrices with the vector of percentage of RVs (PRV)

$$\text{PRV} := \begin{pmatrix} 2 \\ 4 \\ 5 \\ 6 \\ 8 \\ 10 \\ 15 \\ 20 \\ 25 \end{pmatrix} \quad \text{ER23} := \begin{pmatrix} 1.2 & 3 \\ 1.2 & 1.5 \\ 1.2 & 1.5 \\ 1.2 & 1.5 \\ 1.2 & 1.5 \\ 1.2 & 1.5 \\ 1.2 & 1.2 \\ 1.2 & 1.2 \\ 1.2 & 1.2 \end{pmatrix} \quad \text{ER34} := \begin{pmatrix} 1.2 & 2.5 & 3 \\ 1.2 & 2.5 & 2.5 \\ 1.2 & 2 & 2.5 \\ 1.2 & 2 & 2.5 \\ 1.2 & 2 & 2 \\ 1.2 & 2 & 2 \\ 1.2 & 1.5 & 2 \\ 1.2 & 1.5 & 1.5 \\ 1.2 & 1.5 & 1.5 \end{pmatrix} \quad \text{ER45} := \begin{pmatrix} 2.5 & 4 & 4.5 \\ 2 & 3 & 3.5 \\ 2 & 3 & 3 \\ 2 & 3 & 3 \\ 1.5 & 2.5 & 3 \\ 1.5 & 2.5 & 2.5 \\ 1.5 & 2 & 2.5 \\ 1.5 & 2 & 2 \\ 1.5 & 2 & 2 \end{pmatrix} \quad \text{ER5} := \begin{pmatrix} 4 & 6 & 6 \\ 3 & 4 & 4.5 \\ 2.5 & 4 & 4 \\ 2.5 & 3.5 & 4 \\ 2.5 & 3 & 3.5 \\ 2 & 3 & 3 \\ 2 & 2.5 & 3 \\ 2 & 2.5 & 2.5 \\ 1.5 & 2 & 2 \end{pmatrix}$$

Passenger-Car equivalents of RVs (see Exhibit 23-8 and Exhibit 23-10)

If no specific grade exists (Grade = 1), the second row of Exhibit 23-8 is used to define the E_R value. If specific upgrades exists (Grade = 2), the Exhibit 23-10 is used, and if specific downgrades exists (Grade = 3), the grade is treated as level terrain (see Page 23-11)

$$E_R := \begin{cases} \text{if Grade} = 1 \\ \quad \begin{cases} 1.2 & \text{if Gt} = 1 \\ 2.0 & \text{if Gt} = 2 \\ 4.0 & \text{if Gt} = 3 \end{cases} \\ \text{if Grade} = 2 \\ \quad \begin{cases} 1.2 & \text{if (UpDown} \leq 2\%) \\ \text{if } 2\% < \text{UpDown} \leq 3\% \\ \quad \begin{cases} \text{interp}(\text{PRV}, \text{ER23}^{\langle 0 \rangle}, P_R) & \text{if } 0\text{mi} \leq \text{Length} \leq 0.5\text{mi} \\ \text{interp}(\text{PRV}, \text{ER23}^{\langle 1 \rangle}, P_R) & \text{if Length} > 0.5\text{mi} \end{cases} \\ \text{if } 3\% < \text{UpDown} \leq 4\% \\ \quad \begin{cases} \text{interp}(\text{PRV}, \text{ER34}^{\langle 0 \rangle}, P_R) & \text{if } 0\text{mi} \leq \text{Length} \leq 0.25\text{mi} \\ \text{interp}(\text{PRV}, \text{ER34}^{\langle 1 \rangle}, P_R) & \text{if } 0.25\text{mi} \leq \text{Length} \leq 0.5\text{mi} \\ \text{interp}(\text{PRV}, \text{ER34}^{\langle 2 \rangle}, P_R) & \text{if Length} > 0.5\text{mi} \end{cases} \\ \text{if } 4\% < \text{UpDown} \leq 5\% \\ \quad \begin{cases} \text{interp}(\text{PRV}, \text{ER45}^{\langle 0 \rangle}, P_R) & \text{if } 0\text{mi} \leq \text{Length} \leq 0.25\text{mi} \\ \text{interp}(\text{PRV}, \text{ER45}^{\langle 1 \rangle}, P_R) & \text{if } 0.25\text{mi} \leq \text{Length} \leq 0.5\text{mi} \\ \text{interp}(\text{PRV}, \text{ER45}^{\langle 2 \rangle}, P_R) & \text{if Length} > 0.5\text{mi} \end{cases} \\ \text{if UpDown} > 5\% \\ \quad \begin{cases} \text{interp}(\text{PRV}, \text{ER5}^{\langle 0 \rangle}, P_R) & \text{if } 0\text{mi} \leq \text{Length} \leq 0.25\text{mi} \\ \text{interp}(\text{PRV}, \text{ER5}^{\langle 1 \rangle}, P_R) & \text{if } 0.25\text{mi} \leq \text{Length} \leq 0.5\text{mi} \\ \text{interp}(\text{PRV}, \text{ER5}^{\langle 2 \rangle}, P_R) & \text{if Length} > 0.5\text{mi} \end{cases} \\ 1.2 & \text{if Grade} = 3 \end{cases}$$

Gt = 1: Level terrain
 Gt = 2: Rolling terrain
 Gt = 3: Mountainous terrain

The value of E_R is calculated using a linear interpolation of the % RVs (P_R) at the vector PRV and the matrix ER. The grade defines which matrix ET must be used and the length of the grade defines which column of that matrix must be used in the interpolation

Downgrades are treated as level terrain (see Exhibit 23-8)

% of trucks and buses and % of RVs

Convert the % values to decimal values in order to use them in the equations

$$P_T := \frac{P_T}{100}$$

$$P_R := \frac{P_R}{100}$$

Calculate Flow Adjustments

Driver population factor:

$$f_p := 1$$

Passenger-car equivalents for truck/buses:

$$E_T = 1.5$$

Passenger-car equivalents for RVs:

$$E_R = 1.2$$

Heavy-vehicle adjustment factor: $f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)}$ $f_{HV} = 0.925$

Speed Inputs

Lane width	Lw := 12ft
Rt.-shoulder lateral clearance	Rslc := 6ft
Interchange density	Id := 1.5 $\frac{I}{mi}$
Free-flow speed (measured)	FFS := 0mph
Base free-flow speed	BFFS := 70mph

Variables used in this section and not defined in HCM

<i>FID</i> :	vector of adjustments for interchange density
<i>FLC</i> :	matrix of adjustments for right-shoulder lateral clearance
<i>FLW</i> :	vector of adjustments for lane width
<i>FN</i> :	vector of adjustments for number of lanes
<i>FSA</i> :	freeway segment area, 1 for rural areas and 2 for urban areas.
<i>IPM</i> :	vector of interchanges per mile
<i>LW</i> :	vector of lane widths
<i>NL</i> :	vector of number of lanes
<i>RSLC</i> :	vector of right-shoulder lateral clearance

Adjustment for lane width (see Exhibit 23-4)

Two vectors are created, one of lanes widths and one of adjustments for lane width. In order to use the interpolation function (*linterp(vx,vy,x)*) of MathCad, the x vector (*vx*) must be in ascending order. That is the reason why the data is in inverse order as it appears in Exhibit 23-4.

$$LW := \begin{pmatrix} 10 \\ 11 \\ 12 \end{pmatrix} \text{ ft} \quad FLW := \begin{pmatrix} 6.6 \\ 1.9 \\ 0.0 \end{pmatrix} \text{ mph}$$

If there is no FFS measured (FFS = 0mph), f_{LW} is calculated interpolating the lane width (Lw) at the vector LW and FLW. Otherwise f_{LW} is not calculated.

$$f_{LW} := \begin{cases} \text{linterp}(LW, FLW, Lw) & \text{if FFS} = 0\text{mph} \\ 0\text{mph} & \text{otherwise} \end{cases}$$

Function to compute the adjustment for right-shoulder lateral clearance (see Exhibit 23-5)

A vector of right-shoulder lateral clearance and a matrix of adjustments for right-shoulder lateral clearance are created. In order to use the interpolation function (*linterp(vx,vy,x)*) of MathCad, the x vector (*vx*) must be in ascending order. That is the reason why the data is in inverse order as it appears in Exhibit 23-5.

$$RSLC := \begin{pmatrix} 0 \\ 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{pmatrix} \text{ ft} \quad FLC := \begin{pmatrix} 3.6 & 2.4 & 1.2 & 0.6 \\ 3.0 & 2.0 & 1.0 & 0.5 \\ 2.4 & 1.6 & 0.8 & 0.4 \\ 1.8 & 1.2 & 0.6 & 0.3 \\ 1.2 & 0.8 & 0.4 & 0.2 \\ 0.6 & 0.4 & 0.2 & 0.1 \\ 0.0 & 0.0 & 0.0 & 0.0 \end{pmatrix} \text{ mph}$$

If there is no FFS measured (FFS = 0mph), f_{LC} is calculated interpolating the Rt.-shoulder lateral clearance (Rslc) at the vector RSLC and matrix FLC. Otherwise f_{LC} is not calculated.

If the number of lanes in one direction is greater than 5 ($N > 5$), the last column of the matrix FLC is used for the interpolation.

If Rslc is greater than 6, the first row of the matrix FLC is used. All the elements of that row are 0, therefore for any Rslc greater than 6, f_{LC} is 0 (0.0mph otherwise)

$$f_{LC}(N) := \begin{cases} \text{if FFS} = 0\text{mph} \\ \quad \text{if } 0\text{ft} \leq \text{Rslc} \leq 6\text{ft} \\ \quad \quad \text{linterp}(\text{RSLC}, \text{FLC}^{\langle N-2 \rangle}, \text{Rslc}) & \text{if } 2 \leq N \leq 5 \\ \quad \quad \text{linterp}(\text{RSLC}, \text{FLC}^{\langle 3 \rangle}, \text{Rslc}) & \text{if } N > 5 \\ \quad 0.0\text{mph} & \text{otherwise} \\ 0\text{mph} & \text{otherwise} \end{cases}$$

Adjustment for interchange density (see Exhibit 23-7)

Two vectors are created, one of interchanges per mile and one of adjustments for interchange density.

$$\text{IPM} := \begin{pmatrix} 0.50 \\ 0.75 \\ 1.00 \\ 1.25 \\ 1.50 \\ 1.75 \\ 2.00 \end{pmatrix} \frac{\text{I}}{\text{mi}} \quad \text{FID} := \begin{pmatrix} 0.0 \\ 1.3 \\ 2.5 \\ 3.7 \\ 5.0 \\ 6.3 \\ 7.5 \end{pmatrix} \text{mph}$$

If there is no FFS measured (FFS = 0mph), f_{ID} is calculated interpolating the interchange density (Id) at the vector IPM and FID. Otherwise f_{ID} is not calculated.

$$f_{ID} := \begin{cases} \text{linterp}(\text{IPM}, \text{FID}, \text{Id}) & \text{if FFS} = 0\text{mph} \\ 0\text{mph} & \text{otherwise} \end{cases}$$

Function to compute the adjustment for number of lanes (see Exhibit 23-6)

Two vectors are created, one of number of lanes and one of adjustments for number of lanes. In order to use the interpolation function ($\text{linterp}(vx,vy,x)$) of MathCad, the x vector (vx) must be in ascending order. That is the reason why the data is in inverse order as it appears in Exhibit 23-6.

$$\text{FN} := \begin{pmatrix} 4.5 \\ 3.0 \\ 1.5 \\ 0.0 \end{pmatrix} \text{mph} \quad \text{NL} := \begin{pmatrix} 2 \\ 3 \\ 4 \\ 5 \end{pmatrix}$$

f_N is calculated only if FFS is not measured (FFS = 0mph), otherwise f_N is 0. f_N is 0 for rural freeway segments (FSA = 1). For urban areas (FSA = 2), f_N is calculated interpolating the number of lanes (N) at the vector NL and FN.

$$f_N(N) := \begin{cases} \text{if FFS} = 0\text{mph} \\ \left| \begin{array}{l} 0.0\text{mph if FSA} = 1 \\ \text{if FSA} = 2 \\ \left| \begin{array}{l} \text{linterp(NL, FN, N) if } 2 \leq N \leq 5 \\ 0.0\text{mph otherwise} \end{array} \right. \\ 0\text{mph otherwise} \end{array} \right. \end{cases}$$

Function to compute the 15-min passenger-car equivalent flow rate (see Equation 23-2)

If the annual avg. daily traffic is not provided (ADDT = 0), v_p is computed using the hourly volume (V). Otherwise v_p is computed using the directional design-hour volume (DDHV), which is computed in the Flow Input section of the worksheet.

$$V_p(N) := \begin{cases} \frac{V}{\text{PHF} \cdot N \cdot f_{HV} \cdot f_p} & \text{if ADDT} = 0 \\ \frac{\text{DDHV}}{\text{PHF} \cdot N \cdot f_{HV} \cdot f_p} & \text{otherwise} \end{cases}$$

Function to compute the average passenger-car speed (see Exhibit 23-3)

S is computed using the equations presented in the note of Exhibit 23-3. Units have been added to the ranges of values of v_p and FFS. These ranges define when each of the equations is applicable. The units of v_p and FFS are removed to perform the computations.

$$S(\text{FFS}, V_p) := \begin{cases} \text{if } 70\text{mph} < \text{FFS} \leq 75\text{mph} \\ \left| \begin{array}{l} \text{FFS if } 0 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} \leq V_p \leq \left(3400 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} - 30 \cdot \frac{\text{pc}}{\text{mi} \cdot \text{ln}} \cdot \text{FFS} \right) \\ \left[\text{FFS} - \left(\text{FFS} - \frac{160}{3} \text{mph} \right) \cdot \left(\frac{\frac{V_p}{1 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} + 30 \cdot \frac{\text{FFS}}{1\text{mph}} - 3400}{30 \cdot \frac{\text{FFS}}{1\text{mph}} - 1000} \right)^{2.6} \right] \text{ if } \left(3400 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} - 30 \cdot \frac{\text{pc}}{\text{mi} \cdot \text{ln}} \cdot \text{FFS} \right) \end{array} \right. \\ \text{if } 55\text{mph} \leq \text{FFS} \leq 70 \cdot \text{mph} \\ \left| \begin{array}{l} \text{FFS if } 0 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} \leq V_p \leq \left(3400 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} - 30 \cdot \frac{\text{pc}}{\text{mi} \cdot \text{ln}} \cdot \text{FFS} \right) \\ \left[\text{FFS} - \left(\frac{1}{9} \cdot (7 \cdot \text{FFS} - 340\text{mph}) \cdot \left(\frac{\frac{V_p}{1 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} + 30 \cdot \frac{\text{FFS}}{1\text{mph}} - 3400}{40 \cdot \frac{\text{FFS}}{1\text{mph}} - 1700} \right)^{2.6} \right) \right] \text{ if } \left(3400 \cdot \frac{\text{pc}}{\text{hr} \cdot \text{ln}} - 30 \cdot \frac{\text{pc}}{\text{mi} \cdot \text{ln}} \cdot \text{FFS} \right) \end{array} \right. \\ 0\text{mph otherwise} \end{cases}$$

Function to compute the Density (see Equation 23-4)

$$D(S, V_p) := \begin{cases} \frac{V_p}{S} & \text{if } S \neq 0\text{mph} \\ 0 - \frac{pc}{mi \cdot ln} & \text{otherwise} \end{cases}$$

Function to compute the Level of service (see Page 23-3)

If v_p is greater than 2400 pc/hr/ln the LOS is "Oversaturated" ("O")

$$LOS(D, V_p) := \begin{cases} \text{if } 0 - \frac{pc}{hr \cdot ln} \leq V_p \leq 2400 \frac{pc}{hr \cdot ln} \\ \quad \begin{cases} \text{"A"} & \text{if } 0 - \frac{pc}{mi \cdot ln} \leq D \leq 11 \frac{pc}{mi \cdot ln} \\ \text{"B"} & \text{if } 11 \frac{pc}{mi \cdot ln} < D \leq 18 \frac{pc}{mi \cdot ln} \\ \text{"C"} & \text{if } 18 \frac{pc}{mi \cdot ln} < D \leq 26 \frac{pc}{mi \cdot ln} \\ \text{"D"} & \text{if } 26 \frac{pc}{mi \cdot ln} < D \leq 35 \frac{pc}{mi \cdot ln} \\ \text{"E"} & \text{if } 35 \frac{pc}{mi \cdot ln} < D \leq 45 \frac{pc}{mi \cdot ln} \\ \text{"F"} & \text{if } D > 45 \frac{pc}{mi \cdot ln} \end{cases} \\ \text{"O"} & \text{otherwise} \end{cases}$$

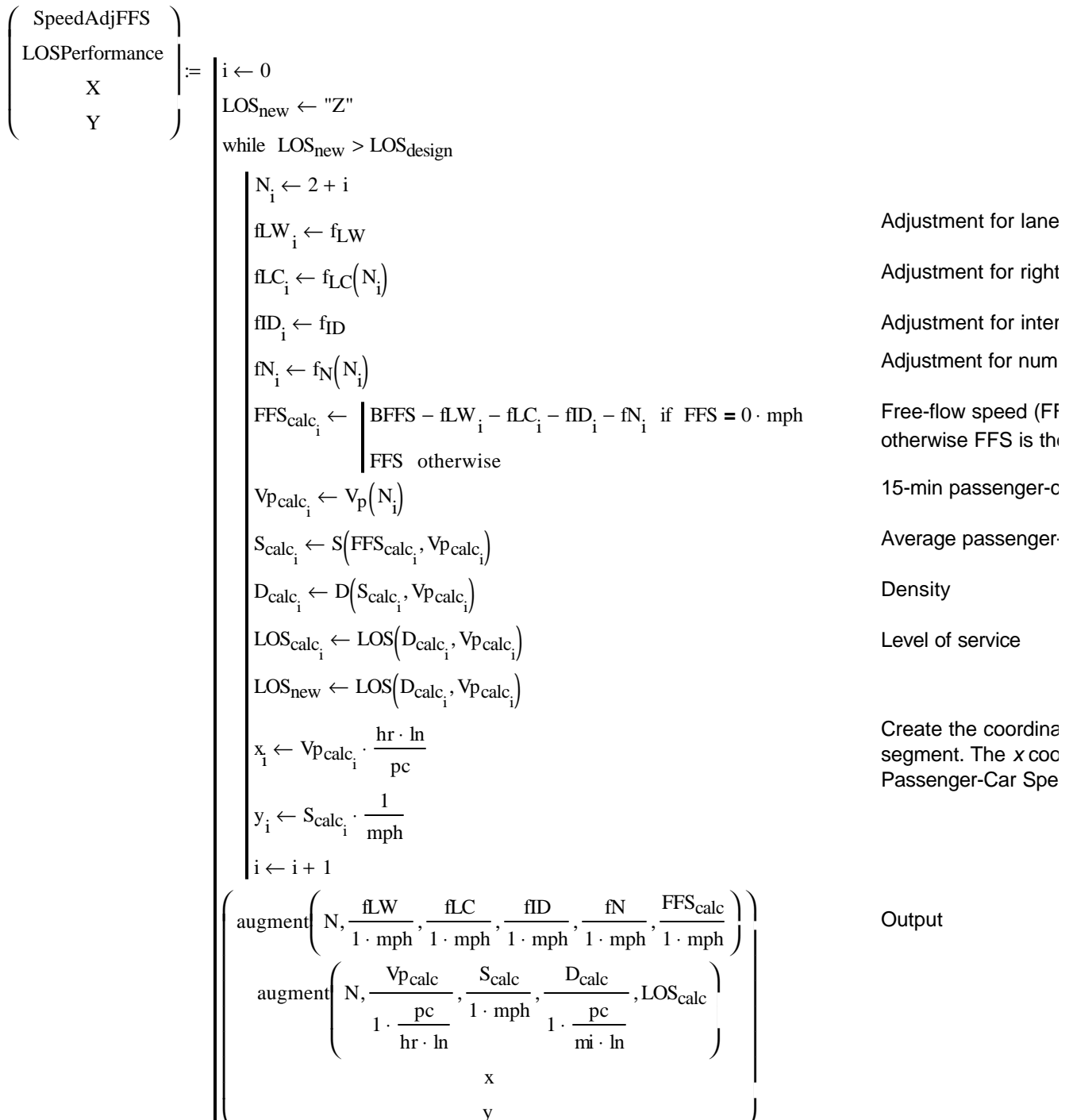
Desired level of service

Convert the desired LOS from the number assigned by the list box (see inputs) to its equivalent in letters (HCM definition).

$$LOS_{design} := \begin{cases} \text{"A"} & \text{if } LOS_{Design} = 1 \\ \text{"B"} & \text{if } LOS_{Design} = 2 \\ \text{"C"} & \text{if } LOS_{Design} = 3 \\ \text{"D"} & \text{if } LOS_{Design} = 4 \\ \text{"E"} & \text{if } LOS_{Design} = 5 \\ \text{"F"} & \text{if } LOS_{Design} = 6 \end{cases}$$

Calculation of Number of Lanes required, N

The procedure starts with an $N = 2$. A LOS is calculated for that N , and then compared to the desired LOS. If the calculated LOS is less (better) or equal to the desired LOS the procedure stops, otherwise N is increased by 1 and the procedure is computed again. The procedure returns a matrix with the speed adjustments and FFS (SpeedAdjFFS) for each iteration, a matrix with the LOS and performance measures (LOSPerformance) for each iteration and the coordinates to plot the Average Passenger-Car Speed vs. the Flow Rate for each of the iterations.



Speed Adjustments and FFS

Number of lanes, N

Adjustment for lane width (mph), f_{LW}

Adjustment for right-shoulder lateral clearance (mph), f_{LC}

Adjustment for interchange density (mph), f_{ID}

Adjustment for number of lanes (mph), f_N

Free-flow speed (mph), FFS

2	3	4	5
0	0	0	0
0	0	0	0
5	5	5	5
0	0	0	0
65	65	65	65

SpeedAdjFFS^T =

LOS and Performance Measures

Number of lanes, N

15-min passenger-car equivalent flow rate (pc/h/ln), V_p

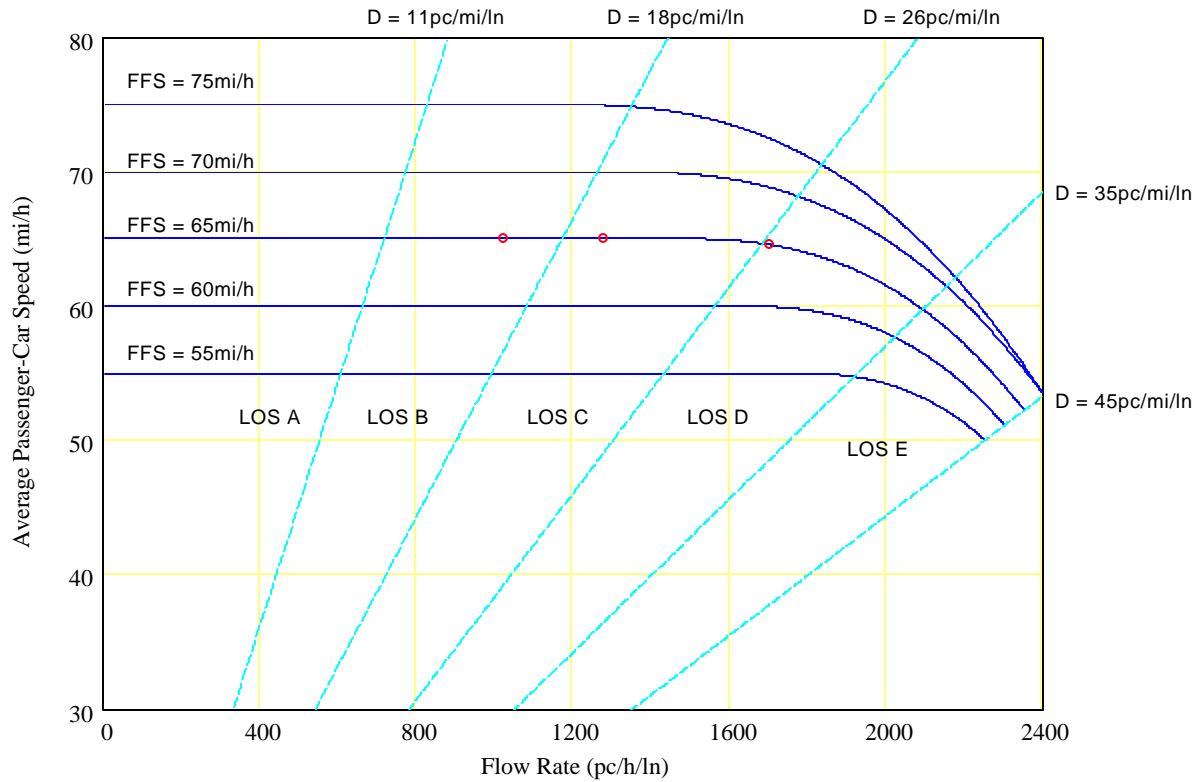
Average passenger-car speed (mph), S

Density (pc/mi/ln), D

Level of service, LOS

	2	3	4	5
2543.5	1695.7	1271.8	1017.4	
0	64.6	65	65	
0	26.3	19.6	15.7	
"O"	"D"	"C"	"B"	

LOS Performance^T =



Note: to see all annotations, right-click on the graph and choose "Send to Back"