Basic Freeway Segments Worksheet
Level of Service (LOS)

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.

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

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.

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

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

Flow Inputs

Volume: $V := 2000 \frac{veh}{hr}$

Peak-hour factor: $PHF := 0.92$

Annual avg. daily traffic[1]: $ADDT := 0 \frac{veh}{day}$

Peak-hour proportion of ADDT: $K := 0$

Peak-hour direction proportion: $D := 0$

Directional design-hour volume:

$DDHV := ADDT \cdot K \cdot D \cdot \frac{day}{hr}$ $DDHV = 0 \frac{veh}{hr}$

Driver type: (•) Commuter/Weekday ( ) Recreational/Weekend

% Trucks and buses: $P_T := 5$

% RVs: $P_R := 0$

General terrain: Rolling

Grade: None

$Length := 0mi$

$UpDown := 0\%$

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)

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

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

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).

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

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

If no specific grade exists ($\text{Grade} = 1$), the first row of Exhibit 23-8 is used to define the E_T value. If specific upgrades exists ($\text{Grade} = 2$), the Exhibit 23-9 is used and if specific downgrades exists ($\text{Grade} = 3$), 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 $2\% \le UpDown \le 3\%$
  - $\text{linterp}\left(PTB, ET23^{\langle 0 \rangle}, P_T\right)$ if $0mi \le Length \le 0.25mi$
  - $\text{linterp}\left(PTB, ET23^{\langle 1 \rangle}, P_T\right)$ if $0.25mi < Length \le 0.5mi$
  - $\text{linterp}\left(PTB, ET23^{\langle 2 \rangle}, P_T\right)$ if $0.5mi < Length \le 0.75mi$
  - $\text{linterp}\left(PTB, ET23^{\langle 3 \rangle}, P_T\right)$ if $0.75mi < Length \le 1mi$
  - $\text{linterp}\left(PTB, ET23^{\langle 4 \rangle}, P_T\right)$ if $1mi < Length \le 1.5mi$
  - $\text{linterp}\left(PTB, ET23^{\langle 5 \rangle}, P_T\right)$ if $Length > 1.5mi$
- if $3\% < UpDown \le 4\%$
  - $\text{linterp}\left(PTB, ET34^{\langle 0 \rangle}, P_T\right)$ if $0mi \le Length \le 0.25mi$
  - $\text{linterp}\left(PTB, ET34^{\langle 1 \rangle}, P_T\right)$ if $0.25mi < Length \le 0.5mi$
  - $\text{linterp}\left(PTB, ET34^{\langle 2 \rangle}, P_T\right)$ if $0.5mi < Length \le 0.75mi$
  - $\text{linterp}\left(PTB, ET34^{\langle 3 \rangle}, P_T\right)$ if $0.75mi < Length \le 1mi$
  - $\text{linterp}\left(PTB, ET34^{\langle 4 \rangle}, P_T\right)$ if $1mi < Length \le 1.5mi$
  - $\text{linterp}\left(PTB, ET34^{\langle 5 \rangle}, P_T\right)$ if $Length > 1.5mi$
- if $4\% < UpDown \le 5\%$
  - $\text{linterp}\left(PTB, ET45^{\langle 0 \rangle}, P_T\right)$ if $0mi \le Length \le 0.25mi$
  - $\text{linterp}\left(PTB, ET45^{\langle 1 \rangle}, P_T\right)$ if $0.25mi < Length \le 0.5mi$
  - $\text{linterp}\left(PTB, ET45^{\langle 2 \rangle}, P_T\right)$ if $0.5mi < Length \le 0.75mi$
  - $\text{linterp}\left(PTB, ET45^{\langle 3 \rangle}, P_T\right)$ if $0.75mi < Length \le 1mi$
  - $\text{linterp}\left(PTB, ET45^{\langle 4 \rangle}, P_T\right)$ if $Length > 1mi$
- if $5\% < UpDown \le 6\%$
  - $\text{linterp}\left(PTB, ET56^{\langle 0 \rangle}, P_T\right)$ if $0mi \le Length \le 0.25mi$
  - $\text{linterp}\left(PTB, ET56^{\langle 1 \rangle}, P_T\right)$ if $0.25mi < Length \le 0.3mi$
  - $\text{linterp}\left(PTB, ET56^{\langle 2 \rangle}, P_T\right)$ if $0.3mi < Length \le 0.5mi$
  - $\text{linterp}\left(PTB, ET56^{\langle 3 \rangle}, P_T\right)$ if $0.5mi < Length \le 0.75mi$

The value of E_T is calculated
linear interpolation of the % t
and buses (P_T) at the vector
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

$\text{linterp}\left(PTB, ET56^{\langle 4\rangle}, P_T\right)$ if $0.75mi < Length \le 1mi$

$\text{linterp}\left(PTB, ET56^{\langle 5\rangle}, P_T\right)$ if $Length > 1mi$

if $UpDown > 6\%$

$\text{linterp}\left(PTB, ET6^{\langle 0\rangle}, P_T\right)$ if $0mi \le Length \le 0.25mi$

$\text{linterp}\left(PTB, ET6^{\langle 1\rangle}, P_T\right)$ if $0.25mi < Length \le 0.3mi$

$\text{linterp}\left(PTB, ET6^{\langle 2\rangle}, P_T\right)$ if $0.3mi < Length \le 0.5mi$

$\text{linterp}\left(PTB, ET6^{\langle 3\rangle}, P_T\right)$ if $0.5mi < Length \le 0.75mi$

$\text{linterp}\left(PTB, ET6^{\langle 4\rangle}, P_T\right)$ if $0.75mi < Length \le 1mi$

$\text{linterp}\left(PTB, ET6^{\langle 5\rangle}, P_T\right)$ if $Length > 1mi$

if $Grade = 3$

1.5 if $(UpDown < 4\%)$

1.5 if $(4\% \le UpDown \le 5\%) \wedge Length \le 4mi$

$\text{linterp}\left(PT, ET46^{\langle 0\rangle}, P_T\right)$ if $(4\% \le UpDown \le 5\%) \wedge Length > 4mi$

1.5 if $(5\% < UpDown \le 6\%) \wedge Length \le 4mi$

$\text{linterp}\left(PT, ET46^{\langle 1\rangle}, P_T\right)$ if $(5\% < UpDown \le 6\%) \wedge Length > 4mi$

1.5 if $UpDown > 6\% \wedge Length \le 4mi$

$\text{linterp}\left(PT, ET46^{\langle 2\rangle}, P_T\right)$ if $UpDown > 6\% \wedge Length > 4mi$

The value of E_T is calculated linear interpolation of the % t and buses (P_T) at the vector 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)

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

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*)

$$
E_R := \left|
\begin{array}{l}
\text{if } Grade = 1 \\
\quad \left| \begin{array}{l} 1.2 \text{ if } Gt = 1 \\ 2.0 \text{ if } Gt = 2 \\ 4.0 \text{ if } Gt = 3 \end{array} \right. \\
\text{if } Grade = 2 \\
\quad \left| \begin{array}{l}
1.2 \text{ if } (UpDown \le 2\%) \\
\text{if } 2\% < UpDown \le 3\% \\
\quad \left| \begin{array}{l}
\text{linterp}\left(PRV, ER23^{\langle 0 \rangle}, P_R\right) \text{ if } 0mi \le Length \le 0.5mi \\
\text{linterp}\left(PRV, ER23^{\langle 1 \rangle}, P_R\right) \text{ if } Length > 0.5mi
\end{array} \right. \\
\text{if } 3\% < UpDown \le 4\% \\
\quad \left| \begin{array}{l}
\text{linterp}\left(PRV, ER34^{\langle 0 \rangle}, P_R\right) \text{ if } 0mi \le Length \le 0.25mi \\
\text{linterp}\left(PRV, ER34^{\langle 1 \rangle}, P_R\right) \text{ if } 0.25mi \le Length \le 0.5mi \\
\text{linterp}\left(PRV, ER34^{\langle 2 \rangle}, P_R\right) \text{ if } Length > 0.5mi
\end{array} \right. \\
\text{if } 4\% < UpDown \le 5\% \\
\quad \left| \begin{array}{l}
\text{linterp}\left(PRV, ER45^{\langle 0 \rangle}, P_R\right) \text{ if } 0mi \le Length \le 0.25mi \\
\text{linterp}\left(PRV, ER45^{\langle 1 \rangle}, P_R\right) \text{ if } 0.25mi \le Length \le 0.5mi \\
\text{linterp}\left(PRV, ER45^{\langle 2 \rangle}, P_R\right) \text{ if } Length > 0.5mi
\end{array} \right. \\
\text{if } UpDown > 5\% \\
\quad \left| \begin{array}{l}
\text{linterp}\left(PRV, ER5^{\langle 0 \rangle}, P_R\right) \text{ if } 0mi \le Length \le 0.25mi \\
\text{linterp}\left(PRV, ER5^{\langle 1 \rangle}, P_R\right) \text{ if } 0.25mi \le Length \le 0.5mi \\
\text{linterp}\left(PRV, ER5^{\langle 2 \rangle}, P_R\right) \text{ if } Length > 0.5mi
\end{array} \right.
\end{array} \right. \\
1.2 \text{ if } Grade = 3
\end{array} \right.
$$

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: $E_T = 2.5$

Passenger-car equivalents for RVs: $E_R = 2$

Heavy-vehicle adjustment factor: $f_{HV} := \frac{1}{1 + P_T \cdot \left(E_T - 1\right) + P_R \cdot \left(E_R - 1\right)}$ $f_{HV} = 0.93$

Speed Inputs

Lane width	$Lw := 11ft$
Rt.-shoulder lateral clearance	$Rslc := 2ft$
Interchange density	$Id := 1\frac{I}{mi}$
Number of lanes	$N := 2$
Free-flow speed (measured)	$FFS := 0mph$
Base free-flow speed	$BFFS := 75mph$

Variables used in this section and not defined in HCM

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

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

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.

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

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.

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

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 ($0.0mph \;\; otherwise$)

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

Adjustments for interchange density (*see Exhibit 23-7*)

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

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

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.

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

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 (*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.

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

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.

$$f_N := \begin{cases} \text{if } FFS = 0\text{mph} \\ \quad \begin{cases} 0.0\text{mph} & \text{if } FSA = 1 \\ \text{if } FSA = 2 \\ \quad \begin{cases} \text{linterp}(NL, FN, N) & \text{if } 2 \le N \le 5 \\ 0.0\text{mph} & \text{otherwise} \end{cases} \end{cases} \\ 0\text{mph} \quad \text{otherwise} \end{cases}$$

Free-flow speed (*see Equation 23-1*)

FFS is calculated only if there is no FFS measured ($FFS = 0\text{mph}$), otherwise FFS is the value measured.

$$FFS := \begin{cases} BFFS - f_{LW} - f_{LC} - f_{ID} - f_N & \text{if } FFS = 0\text{mph} \\ FFS & \text{otherwise} \end{cases}$$

Calculate Speed Adjustments and FFS

Adjustment for Lane Width (Exhibit 23-4):	$f_{LW} = 1.9\,\text{mph}$
Adjustment for Right-Shoulder Lateral Clearance (Exhibit 23-5):	$f_{LC} = 2.4\,\text{mph}$
Adjustment for Interchange Density (Exhibit 23-7):	$f_{ID} = 2.5\,\text{mph}$
Adjustment for Number of Lanes (Exhibit 23-6):	$f_N = 0\,\text{mph}$
FSS = BFFS - f_{LW} - f_{LC} - f_{ID} - f_N	$FFS = 68.2\,\text{mph}$

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.

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

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.

$$S := \begin{cases} \text{if } 70\text{mph} < FFS \le 75\text{mph} \\ \quad \begin{cases} FFS & \text{if } 0 \cdot \dfrac{pc}{hr \cdot ln} \le V_p \le \left(3400 \cdot \dfrac{pc}{hr \cdot ln} - 30 \cdot \dfrac{pc}{mi \cdot ln} \cdot FFS\right) \\ FFS - \left[\left(FFS - \dfrac{160}{\cdots}\text{mph}\right) \cdot \left(\dfrac{\dfrac{V_p}{1\dfrac{pc}{hr \cdot ln}} + 30\dfrac{FFS}{1\text{mph}} - 3400}{\cdots}\right)^{2.6}\right] & \text{if } \left(3400 \cdot \dfrac{pc}{\cdots} - 30 \cdot \dfrac{pc}{\cdots} \cdot FFS\right) < V_p \le 2\cdots \end{cases} \end{cases}$$

$$\left[\left(\quad 3 \quad \right) \left(30 \cdot \frac{FFS}{1mph} - 1000 \right) \right] \quad \left(\quad hr \cdot ln \quad mi \cdot ln \quad \right)$$

$$\begin{array}{l} \text{if } 55mph \le FFS \le 70 \cdot mph \\ \quad \left| \begin{array}{l} FFS \ \text{ if } 0 \cdot \frac{pc}{hr \cdot ln} \le V_p \le \left(3400 \cdot \frac{pc}{hr \cdot ln} - 30 \cdot \frac{pc}{mi \cdot ln} \cdot FFS \right) \\ FFS - \left[\frac{1}{9} \cdot (7 \cdot FFS - 340mph) \cdot \left(\frac{\frac{V_p}{1\frac{pc}{hr \cdot ln}} + 30 \cdot \frac{FFS}{1mph} - 3400}{40 \cdot \frac{FFS}{1mph} - 1700} \right)^{2.6} \right] \ \text{ if } \left(3400 \cdot \frac{pc}{hr \cdot ln} - 30 \cdot \frac{pc}{mi \cdot ln} \cdot FFS \right) \le V \end{array} \right. \\ 0mph \ \text{ otherwise} \end{array}$$

Density (*see Equation 23-4*)

$$D := \left| \begin{array}{l} \frac{V_p}{S} \ \text{ if } S \ne 0mph \\ 0 \ \text{ otherwise} \end{array} \right.$$

Level of service (*see Page 23-3*)

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

$$LOS := \left| \begin{array}{l} \text{if } 0\frac{pc}{hr \cdot ln} \le V_p \le 2400\frac{pc}{hr \cdot ln} \\ \quad \left| \begin{array}{l} \text{"A" if } 0\frac{pc}{mi \cdot ln} \le D \le 11\frac{pc}{mi \cdot ln} \\ \text{"B" if } 11\frac{pc}{mi \cdot ln} < D \le 18\frac{pc}{mi \cdot ln} \\ \text{"C" if } 18\frac{pc}{mi \cdot ln} < D \le 26\frac{pc}{mi \cdot ln} \\ \text{"D" if } 26\frac{pc}{mi \cdot ln} < D \le 35\frac{pc}{mi \cdot ln} \\ \text{"E" if } 35\frac{pc}{mi \cdot ln} < D \le 45\frac{pc}{mi \cdot ln} \\ \text{"F" if } D > 45\frac{pc}{mi \cdot ln} \end{array} \right. \\ \text{"Oversaturated" otherwise} \end{array} \right.$$

Coordinates

Create the coordinates of the point corresponding to the characteristics of the freeway segment.
The *x* coordinate is the Flow Rate and the *y* coordinate is Average Passenger-Car Speed. The units are removed.

$$x := V_p \cdot \frac{hr \cdot ln}{pc}$$

$$y := S \cdot \frac{1}{mph}$$

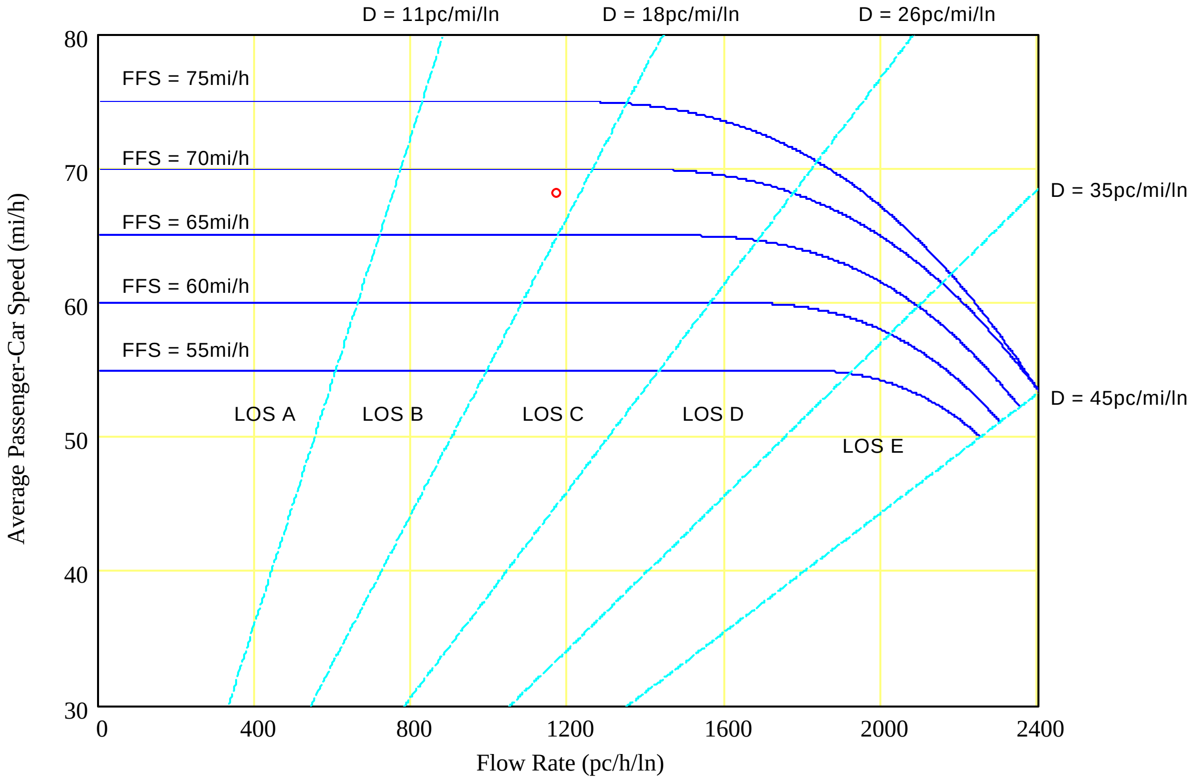
LOS and Performance Measures

Flow rate: $V_p = \dfrac{VorDDHV}{PHF \cdot N \cdot f_{HV} \cdot f_p}$ $\qquad V_p = 1168 \dfrac{pc}{hr \cdot ln}$

Average passenger-car speed: $S = 68.2\,mph$

Density: $D := \dfrac{V_p}{S}$ $\qquad D = 17.1 \dfrac{pc}{mi \cdot ln}$

Level of service: LOS = "B"



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