1. Basic

Input Values

**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).*

Traffic

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

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

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

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

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

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

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

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

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

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

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

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

$S = 65.0$

Density (using Eq. 23-4)

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

Determine level of service (using Exhibit 23-2)

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

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

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.*

2. Off-Ramp

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

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

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

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 3962 \text{ ft}$$

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

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

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

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.645$$

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

$$P_{FD}(Numlanes) := \left| \begin{array}{l}
out \leftarrow 1.00 \text{ if } NumLanes = 2 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 0 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn2, Eqn3) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn2, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn3, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow 0.436 \text{ if } NumLanes = 4
\end{array} \right.$$

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

C. Estimating Flow in Lanes 1 and 2

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

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

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

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

C. Final Flow in Lanes 1 and 2

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

Step 3. Determine Capacity of Ramp-Freeway Junction

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

$CapUpFreewaySegment(NumLanes, FFS) = 7050$ Capacity of Ramp Freeway Junction

$MaxV12 = 4400$ Maximum Desirable Flow Rate Entering Merge Influence Area

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

$CapacityRampRoadway = 2000$

$V_f = 3276$ 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

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

B. Density in Outer Lanes

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

C. Density of Entire Cross-Section

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

$Density = 17.9$ 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

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

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

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

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

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

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

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

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

**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.*

3. Basic

**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).*

Input Values

Traffic

$FwyVol := 2736 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.9$

$\%Trucks_F := 5.3289 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0533$$

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

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

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$$

$L_{midpnts} = 1000$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.974$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 985.6 \ \text{pc/h/ln}$$

Determine the Speed

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

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

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

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

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

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

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 64.0$ mi/h

$$S := \begin{array}{|l} S_{avg} \text{ if } S_{avg} \le S_{max} \\ S_{max} \text{ if } S_{avg} > S_{max} \end{array}$$

$S = 64.0$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 15.4$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2736$

$\%Trucks_{FNew} := \%Trucks_F = 5.3289$

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

4. Weaving

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

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

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

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1750 \text{ ft}$$

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 2956.736 \qquad OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 483.737$$

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

**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*

$$f\_HV := \frac{(f\_HV\_FF + f\_HV\_FR + f\_HV\_RF + f\_HV\_RR)}{4} \qquad f\_HV = 0.986$$

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

$$VR := \frac{WeavingFlowRate}{TotalFlowRate} \qquad VR = 0.312$$

Step 3. Determine the Maximum Weaving Length

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

$MaximumLength = 5710$ ft $\qquad Ls := L_B \cdot .77 = 2310$

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

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

$C\_IWL = 2090$ 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

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

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

$C\_IW := C\_IW(N\_WL)$ $C\_IW = 7700$ 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

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

$WeavingCapacity = 7593$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$VolumeToCapacity = 0.481$

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

Step 5. Determine Configuration Characteristics

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

$LC\_MIN := LC\_MIN(Config)$ $LC\_MIN = 1154$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

$LaneChangingWeaving := LC\_W(Ls)$

$LaneChangingWeaving = 1615$ 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

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

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

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

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

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

$LaneChangingNonWeaving = 1006$ 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

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

$WeavingIntensityFactor = 0.25$

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

$AverageWeavingSpeed = 55.01$ mi/h

B. Average Speed of Non-Weaving Vehicles

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

$AverageNonWeavingSpeed = 52.25$ mi/h

C. Average Speed of All Vehicles

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

$AverageSpeed = 53.08$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 64.9$ mi/h

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

$S = 53.1$ mi/h

Step 8. Determine the Level of Service

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

$Density = 17.4$ pc/mi/ln

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

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

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

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

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

$$\%Trucks_{FNew} = 5.055$$

Note: **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.*

5. Basic

Input Values

**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).*

Traffic

$FwyVol := 2981 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 53.1$

$\%Trucks_F := 5.055 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0505$$

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

$L_{seg} := 500$ ft $\quad L_{prev} := 3000$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1750 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9753$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1072.4 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 64.3$ mi/h

$$S := \begin{array}{|l} S_{avg} \;\; \text{if} \;\; S_{avg} \le S_{max} \\ S_{max} \;\; \text{if} \;\; S_{avg} > S_{max} \end{array}$$ $S = 64.3$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 16.7$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2981$

$\%Trucks_{FNew} := \%Trucks_F = 5.055$

**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 %Trucks_FF and %Trucks_FR.*

6. On-Ramp

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

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

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

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

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

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

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

C. Demand Flow Rate

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

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

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

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

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

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

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

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

$$
P_{FM}(Numlanes) := \left|
\begin{array}{l}
out \leftarrow 1.00 \quad \text{if} \quad NumLanes = 2 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp \neq 2 \wedge AdjDn \neq 2 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn1, Eqn2) \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn3, Eqn2) \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad 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) \quad \text{if} \quad 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 \dfrac{L_A}{S_{FR}} \quad \text{if} \quad \left(\dfrac{V_f}{S_{FR}} \leq 72\right) \wedge (NumLanes = 4) \\
out \leftarrow 0.2178 - 0.0000125 \cdot V_r \quad \text{if} \quad \left(\dfrac{V_f}{S_{FR}} > 72\right) \wedge (NumLanes = 4)
\end{array}
\right.
$$

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

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

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

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

CapUpFreewaySegment(NumLanes, FFS) :=

out ← 4800	if	FFS ≥ 70 ∧ NumLanes = 2
out ← 4700	if	FFS = 65 ∧ NumLanes = 2
out ← 4600	if	FFS = 60 ∧ NumLanes = 2
out ← 4600	if	FFS = 55 ∧ NumLanes = 2
out ← 7200	if	FFS = 70 ∧ NumLanes = 3
out ← 7050	if	FFS = 65 ∧ NumLanes = 3
out ← 6900	if	FFS = 60 ∧ NumLanes = 3
out ← 6750	if	FFS = 55 ∧ NumLanes = 3
out ← 9600	if	FFS = 70 ∧ NumLanes = 4
out ← 9400	if	FFS = 65 ∧ NumLanes = 4
out ← 9200	if	FFS = 60 ∧ NumLanes = 4
out ← 9000	if	FFS = 55 ∧ NumLanes = 4
out ← 2400·NumLanes	if	FFS = 70 ∧ NumLanes > 4
out ← 2350·NumLanes	if	FFS = 65 ∧ NumLanes > 4
out ← 2300·NumLanes	if	FFS = 60 ∧ NumLanes > 4
out ← 2250·NumLanes	if	FFS = 55 ∧ NumLanes > 4

CapUpFreewaySegment(NumLanes, FFS) = 7050 Capacity of Ramp Freeway Junction

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

CapacityRampRoadway :=

out ← 2200	if	$(NRamp = 1) \wedge (S_{FR} > 50)$
out ← 2100	if	$(NRamp = 1) \wedge (40 < S_{FR} \le 50)$
out ← 2000	if	$(NRamp = 1) \wedge (30 < S_{FR} \le 40)$
out ← 1900	if	$(NRamp = 1) \wedge (20 \le S_{FR} \le 30)$
out ← 1800	if	$(NRamp = 1) \wedge (20 > S_{FR})$
out ← 4400	if	$(NRamp = 2) \wedge (S_{FR} > 50)$
out ← 4200	if	$(NRamp = 2) \wedge (40 < S_{FR} \le 50)$
out ← 4000	if	$(NRamp = 2) \wedge (30 < S_{FR} \le 40)$
out ← 3800	if	$(NRamp = 2) \wedge (20 \le S_{FR} \le 30)$
out ← 3600	if	$(NRamp = 2) \wedge (20 > S_{FR})$

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

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

$S_R = 58.44$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{No}$$

$V_{OA} = 1269$

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

$S_O := S_O(V_{OA})$ $S_O = 62.23$ mi/h

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)}$$

$S_{avg} = 59.68$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 64.9$ mi/h

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

$S = 59.7$ 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

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

$Density = 18.8$ 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

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

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

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

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

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

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

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

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

**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.*

7. Basic

Input Values

**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).*

Traffic

$FwyVol := 3436 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.7$

$\%Trucks_F := 4.6505 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0465$$

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

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

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

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9773$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1233.6 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 65.0$ mi/h

$$S := \begin{array}{|l} S_{avg} \ \ if \ \ S_{avg} \le S_{max} \\ S_{max} \ \ if \ \ S_{avg} > S_{max} \end{array}$$ $S = 65.0$ mi/h

Density (using Eq. 23-4)

$D := \dfrac{v_p}{S}$ $D = 19$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

$LOS(D) = "C"$

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 3436$

$\%Trucks_{FNew} := \%Trucks_F = 4.6505$

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

8. Off-Ramp

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

$FwyVol := 3436$ veh/h $RampVol := 455$ veh/h

$\%Trucks_F := 4.6505$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ 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

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

$L_{up} := 5280$ ft $L_{down} := 2280$ ft

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

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

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} \qquad f\_HV_F = 0.977$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3701 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 484 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 484 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 744 \text{ pc/h}$$

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 4053 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 872 \text{ ft}$$

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

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.645$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.628$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.579$$

$$P_{FD}(Numlanes) := \begin{array}{|l} out \leftarrow 1.00 \text{ if } NumLanes = 2 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 0 \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 1 \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn3 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow \max(Eqn2, Eqn3) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow \max(Eqn2, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow \max(Eqn3, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn3 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow 0.436 \text{ if } NumLanes = 4 \end{array}$$

$$P_{FD} := P_{FD}(NumLanes) \qquad P_{FD} = 0.645$$

C. Estimating Flow in Lanes 1 and 2

$$V_{12} := V_r + (V_f - V_r) \cdot P_{FD} \qquad V_{12} = 2560 \text{ pc/h}$$

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $\quad V_3 = 1141$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $\quad V_{av34} = 571$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := \text{V12a(NumLanes)}$ $\quad V_{12} = 2560$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

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

$CapUpFreewaySegment(NumLanes, FFS) = 7050$ Capacity of Ramp Freeway Junction

$MaxV12 = 4400$ Maximum Desirable Flow Rate Entering Merge Influence Area

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

$CapacityRampRoadway = 2000$

$V_f = 3701$ 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

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

$S_R = 55.65$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

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

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

$V_{OA} = 1141$

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

$S_O := S_O(V_{OA})$ $S_O = 70.75$ mi/h

C. Average Speed for Off-Ramp Junction

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

$S_{avg} = 59.57$ 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

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

$S = 59.6$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $\qquad Density_R = 22.2$ pc/mi/ln

B. Density in Outer Lanes

$Density_O := \frac{V_{OA}}{S_O}$ $\qquad Density_O = 16.1$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 20.2$ pc/mi/ln

D. Level of Service

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

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

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

$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 3276.2$

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

$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2830.3$

$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 159.791$

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

$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 150.691$

$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2981$

$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.0551$

**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.*

9. Basic

**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).*

Input Values

Traffic

$FwyVol := 2981 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.6$

$\%Trucks_F := 5.0551 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0506$$

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

$L_{seg} := 2280$ ft $\quad L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1890 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9753$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1072.4 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

$$S_{avg} := \begin{cases} out \leftarrow Eqn1 & \text{if } FFS = 75 \wedge v_p > 1000 \\ out \leftarrow Eqn2 & \text{if } FFS = 70 \wedge v_p > 1200 \\ out \leftarrow Eqn3 & \text{if } FFS = 65 \wedge v_p > 1400 \\ out \leftarrow Eqn4 & \text{if } FFS = 60 \wedge v_p > 1600 \\ out \leftarrow Eqn5 & \text{if } FFS = 55 \wedge v_p > 1800 \\ out \leftarrow FFS & \end{cases}$$

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 64.7$ mi/h

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

$S = 64.7$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 16.6$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

$$LOS(D) := \begin{cases} out \leftarrow \text{"F"} & \text{if } D > 45 \\ out \leftarrow \text{"E"} & \text{if } 45 \ge D > 35 \\ out \leftarrow \text{"D"} & \text{if } 35 \ge D > 26 \\ out \leftarrow \text{"C"} & \text{if } 26 \ge D > 18 \\ out \leftarrow \text{"B"} & \text{if } 18 \ge D > 11 \\ out \leftarrow \text{"A"} & \text{if } 11 \ge D \\ out & \end{cases}$$

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2981$

$\%Trucks_{FNew} := \%Trucks_F = 5.0551$

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

10. Weaving

**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.*

Step 1. Data Inputs

OnRampVol := 700 OffRampVol := 700 SegInputVol := 2981 Int_Density := 0.87 int/mi

OnRamp%HV := 2 OffRamp%HV := 2 SegInput%HV := 5.0551

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

FFS := 65 mi/h S_{prev} := 64.7 mi/h PHF := .95 fp := 1

L_B := 4000 ft L_{seg} := 4000 ft L_{prev} := 2280 ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 3140 \text{ ft}$$

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

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

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 3217.207 \qquad OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 744.211$$

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

**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.*

$v\_FR := OffRampVolAdj - v\_RR = 707$ veh/h

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

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

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 3.961 \times 10^{3}$ veh/h

C. Weaving Demand Flow Rate

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

$WeavingFlowRate := WeavingDemand(N\_WL)$

$WeavingFlowRate = 1414$ pc/h

D. Non-Weaving Demand Flow Rate

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

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$NonWeavingFlowRate = 2547$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$TotalFlowRate = 3961$ pc/h

F. Volume Ratio

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

$VR = 0.357$

Step 3. Determine the Maximum Weaving Length

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

$\text{MaximumLength} = 6203$ ft $\qquad$ $\text{Ls} := L_B \cdot .77 = 3080$

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

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

$\text{C\_IWL} = 2111$ pc/h/ln $\qquad$ C_IWL is the capacity per lane under equivalent ideal conditions

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

$\text{Cw1} = 8330$ veh/h $\qquad$ Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

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

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.

$\text{C\_IW} := \text{C\_IW}(\text{N\_WL})$ $\qquad$ $\text{C\_IW} = 6724$ pc/h $\qquad$ C_IW is the capacity of the weaving segment under ideal conditions

$$\text{Cw2} := \text{C\_IW} \cdot \text{f\_HV} \cdot \text{fp}$$

$\text{Cw2} = 6632$ veh/h $\qquad$ Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

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

$\text{WeavingCapacity} = 6632$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$\text{VolumeToCapacity} = 0.589$

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

Step 5. Determine Configuration Characteristics

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

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

$LC\_MIN = 1414$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

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

$LaneChangingWeaving = 1957$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

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

$I\_NW = 683$ Non Weaving Vehicle Index

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

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

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

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

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

$LaneChangingNonWeaving = 1424$ lc/h

C. Total Lane-Changing Rate

$$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$$

$TotalLaneChanging = 3381$ lc/h

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

A. Average Speed of Weaving Vehicles

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

$$WeavingIntensityFactor = 0.243$$

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

$AverageWeavingSpeed = 55.22$ mi/h

B. Average Speed of Non-Weaving Vehicles

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

$AverageNonWeavingSpeed = 50.07$ mi/h

C. Average Speed of All Vehicles

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

$AverageSpeed = 51.79$ 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

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

$S = 51.8$ mi/h

Step 8. Determine the Level of Service

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

$Density = 19.1$ pc/mi/ln

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

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

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

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

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

$\%Trucks_{FNew} = 5.055$

Note: **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.*

11. Basic

Input Values

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).

Traffic

$FwyVol := 2981 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 51.8$

$\%Trucks_F := 5.055 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0505$$

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

$L_{seg} := 2280$ ft $\quad L_{prev} := 4000$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 3140 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9753$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1072.4 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$$S_{avg} = 65.0$$

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

$$S := \begin{array}{|l} S_{avg} \;\; \text{if} \;\; S_{avg} \le S_{max} \\ S_{max} \;\; \text{if} \;\; S_{avg} > S_{max} \end{array} \qquad S = 64.9 \;\; \text{mi/h}$$

Density (using Eq. 23-4)

$$D := \frac{v_p}{S} \qquad D = 16.5 \;\; \text{pc/mi/ln}$$

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$$FwyVolNew := FwyVol = 2981$$

$$\%Trucks_{FNew} := \%Trucks_F = 5.055$$

**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 %Trucks_FF and %Trucks_FR.*

12. On-Ramp

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

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 64.9$ 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 $L_{prev} := 2280$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1890 \text{ ft}$$

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

$L_{up} := 5280$ ft $L_{down} := 3000$ ft

$VolumeUp := 800$ 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

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

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 851 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 484 \text{ pc/h}$$

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

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

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

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

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

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $\quad Eqn2 = 0.88$

$Eqn3 := 0.5487 + 0.2628 \cdot \dfrac{V_d}{L_{down}}$ $\quad Eqn3 = 0.591$

$P_{FM}(Numlanes) :=$

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

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

C. Estimating Flow in Lanes 1 and 2

$V_{12} := V_f \cdot P_{FM}$ $\quad V_{12} = 1948$ 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

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

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

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

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

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

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

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

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

$S_R = 58.44$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{No}$$

$V_{OA} = 1269$

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

$S_O := S_O(V_{OA})$ $S_O = 62.23$ mi/h

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)}$$

$S_{avg} = 59.68$ 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

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

$S = 59.7$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

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

$Density_R = 18$ 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

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

$Density = 18.8$ 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

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

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

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

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

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

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

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

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

**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.*

13. Off-Ramp

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

$FwyVol := 3436$ veh/h $RampVol := 455$ veh/h

$\%Trucks_F := 4.6505$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 59.7$ 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 $L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1500 \text{ ft}$$

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

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

$L_{up} := 3000$ ft $L_{down} := 1500$ ft

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

$VolumeDown := 600$ veh/h Volume on adjacent downstream ramp

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} \qquad f\_HV_F = 0.977$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3701 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 484 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 484 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 638 \text{ pc/h}$$

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 4053 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 748 \text{ ft}$$

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

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.645$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.67$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.591$$

$P_{FD}(Numlanes) :=$

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

$$P_{FD} := P_{FD}(NumLanes) \qquad P_{FD} = 0.67$$

C. Estimating Flow in Lanes 1 and 2

$$V_{12} := V_r + (V_f - V_r) \cdot P_{FD} \qquad V_{12} = 2639 \text{ pc/h}$$

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $V_3 = 1061$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 531$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(NumLanes)$ $V_{12} = 2639$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

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

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

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

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

CapacityRampRoadway = 2000

$V_f = 3701$ 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

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

$S_R = 55.65$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

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

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

$V_{OA} = 1061$

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

$S_O := S_O(V_{OA})$ $S_O = 71.07$ mi/h

C. Average Speed for Off-Ramp Junction

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

$S_{avg} = 59.34$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 64.5$ mi/h

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

$S = 59.3$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $\qquad Density_R = 22.9$ pc/mi/ln

B. Density in Outer Lanes

$Density_O := \frac{V_{OA}}{S_O}$ $\qquad Density_O = 14.9$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 20.2$ pc/mi/ln

D. Level of Service

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

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

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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 3276.2$$

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

$$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2830.3$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 159.791$$

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

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 150.691$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2981$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.0551$$

**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.*

14. Basic

**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).*

Input Values

Traffic

$FwyVol := 2981 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.3$

$\%Trucks_F := 5.0551 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0506$$

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

$L_{seg} := 1500$ ft $\quad L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1500 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9753$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1072.4 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

$$S_{max} := FFS - \left(FFS - S_{prev}\right) \cdot e^{\left(-0.00162 \cdot L_{midpnts}\right)}$$ $S_{max} = 64.5$ mi/h

$$S := \begin{array}{|l} S_{avg} \;\; \text{if} \;\; S_{avg} \le S_{max} \\ S_{max} \;\; \text{if} \;\; S_{avg} > S_{max} \end{array}$$ $S = 64.5$ mi/h

Density (using Eq. 23-4)

$$D := \frac{v_p}{S}$$ $D = 16.6$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2981$

$\%Trucks_{FNew} := \%Trucks_F = 5.0551$

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

15. On-Ramp

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 $RampVol := 600$ veh/h

$\%Trucks_F := 5.0551$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 64.5$ 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 $L_{prev} := 1500$ ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$ $L_{midpnts} = 1500$ 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

$L_{up} := 1500$ ft $L_{down} := 4000$ ft

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

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

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

$$E_R(Terrain) := \begin{vmatrix} out \leftarrow 1.2 & \text{if } Terrain = 1 \\ out \leftarrow 2.0 & \text{if } Terrain = 2 \\ out \leftarrow 4.0 & \text{if } Terrain = 3 \end{vmatrix}$$

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

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

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

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3217 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 638 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 484 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 744 \text{ pc/h}$$

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

$L_{EQup} := 0.214(V_f + V_r) + 0.444 \cdot L_A + 52.32 \cdot S_{FR} - 2403$ $L_{EQup} = 959$ ft

$L_{EQdown} := \dfrac{V_d}{0.1096 + 0.000107 \cdot L_A}$ $L_{EQdown} = 3436$ ft

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

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

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $Eqn2 = 0.64$

$Eqn3 := 0.5487 + 0.2628 \cdot \dfrac{V_d}{L_{down}}$ $Eqn3 = 0.598$

$$
P_{FM}(Numlanes) := \left|
\begin{array}{l}
out \leftarrow 1.00 \quad \text{if} \quad NumLanes = 2 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp \neq 2 \wedge AdjDn \neq 2 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn1, Eqn2) \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn3, Eqn2) \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \quad \text{if} \quad 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) \quad \text{if} \quad 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 \dfrac{L_A}{S_{FR}} \quad \text{if} \quad \left(\dfrac{V_f}{S_{FR}} \leq 72\right) \wedge (NumLanes = 4) \\
out \leftarrow 0.2178 - 0.0000125 \cdot V_r \quad \text{if} \quad \left(\dfrac{V_f}{S_{FR}} > 72\right) \wedge (NumLanes = 4)
\end{array}
\right.
$$

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

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

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

C. Final Flow in Lanes 1 and 2

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

Step 3. Determine Capacity of Ramp-Freeway Junction

$V_{R12} := V_{12} + V_r$ $V_{R12} = 2586$ pc/h Flow entering the ramp influence area

CapUpFreewaySegment(NumLanes , FFS) :=

$$\begin{array}{l}
out \leftarrow 4800 \text{ if } FFS \ge 70 \wedge NumLanes = 2 \\
out \leftarrow 4700 \text{ if } FFS = 65 \wedge NumLanes = 2 \\
out \leftarrow 4600 \text{ if } FFS = 60 \wedge NumLanes = 2 \\
out \leftarrow 4600 \text{ if } FFS = 55 \wedge NumLanes = 2 \\
out \leftarrow 7200 \text{ if } FFS = 70 \wedge NumLanes = 3 \\
out \leftarrow 7050 \text{ if } FFS = 65 \wedge NumLanes = 3 \\
out \leftarrow 6900 \text{ if } FFS = 60 \wedge NumLanes = 3 \\
out \leftarrow 6750 \text{ if } FFS = 55 \wedge NumLanes = 3 \\
out \leftarrow 9600 \text{ if } FFS = 70 \wedge NumLanes = 4 \\
out \leftarrow 9400 \text{ if } FFS = 65 \wedge NumLanes = 4 \\
out \leftarrow 9200 \text{ if } FFS = 60 \wedge NumLanes = 4 \\
out \leftarrow 9000 \text{ if } FFS = 55 \wedge NumLanes = 4 \\
out \leftarrow 2400 \cdot NumLanes \text{ if } FFS = 70 \wedge NumLanes > 4 \\
out \leftarrow 2350 \cdot NumLanes \text{ if } FFS = 65 \wedge NumLanes > 4 \\
out \leftarrow 2300 \cdot NumLanes \text{ if } FFS = 60 \wedge NumLanes > 4 \\
out \leftarrow 2250 \cdot NumLanes \text{ if } FFS = 55 \wedge NumLanes > 4
\end{array}$$

CapUpFreewaySegment(NumLanes , FFS) = 7050 Capacity of Ramp Freeway Junction

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

CapacityRampRoadway :=

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

CapacityRampRoadway = 2000

$V_{FO} := V_f + V_r$ $V_{FO} = 3855$ 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

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

$S_R = 58.27$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{No}$$

$V_{OA} = 1269$

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

$S_O := S_O(V_{OA})$ $S_O = 62.23$ mi/h

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)}$$

$S_{avg} = 59.51$ 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

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

$S = 59.5$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

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

$Density_R = 19.1$ 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

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

$Density = 19.5$ pc/mi/ln

D. Level of Service

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

$LOS(Density) = "B"$

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

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

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 588$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} + RampVol_{Cars} = 3418.3$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 150.693$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 12$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} + RampVol_{Trucks} = 162.693$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 3581$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 4.5432$$

**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.*

16. Basic

Input Values

$FwyVolNew$ and $\%Trucks_{FNew}$ from the previous upstream segment are the input values for FwyVol and $\%Trucks_F$ (if there is a previous upstream segment).

Traffic

$FwyVol := 3581 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.5$

$\%Trucks_F := 4.5432 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0454$$

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

$L_{seg} := 1000$ ft $\quad L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1250 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9778$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1285 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$$S_{avg} = 65.0$$

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 64.3 \text{ mi/h}$$

$$S := \begin{array}{|l} S_{avg} \ \text{ if } \ S_{avg} \le S_{max} \\ S_{max} \ \text{ if } \ S_{avg} > S_{max} \end{array} \qquad S = 64.3 \text{ mi/h}$$

Density (using Eq. 23-4)

$$D := \frac{v_p}{S} \qquad D = 20.0 \text{ pc/mi/ln}$$

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$$FwyVolNew := FwyVol = 3581$$

$$\%Trucks_{FNew} := \%Trucks_F = 4.5432$$

**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.*

17. Off-Ramp

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

$FwyVol := 3581$ veh/h $RampVol := 700$ veh/h

$\%Trucks_F := 4.5432$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ 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 $L_{prev} := 1000$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1250 \text{ ft}$$

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

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

$L_{up} := 4000$ ft $L_{down} := 1500$ ft

$VolumeUp := 600$ veh/h Volume on adjacent upstream ramp

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

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} \qquad f\_HV_F = 0.978$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3855 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 744 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 638 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 484 \text{ pc/h}$$

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 6187 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 643 \text{ ft}$$

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

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.629$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.663$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.575$$

$$P_{FD}(Numlanes) := \left| \begin{array}{l}
out \leftarrow 1.00 \text{ if } NumLanes = 2 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 0 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \ge L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} \ge L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} \ge L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn2, Eqn3) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn2, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \ge L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \ge L_{EQup} \wedge L_{down} \ge L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn3, Eqn1) \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \ge L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} \ge L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow 0.436 \text{ if } NumLanes = 4
\end{array} \right.$$

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

C. Estimating Flow in Lanes 1 and 2

$$V_{12} := V_r + (V_f - V_r) \cdot P_{FD} \qquad V_{12} = 2807 \text{ pc/h}$$

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $V_3 = 1048$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 524$ 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

$V_{12} := V12a(NumLanes)$ $V_{12} = 2807$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

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

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

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

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

$CapacityRampRoadway = 2000$

$V_f = 3855$ 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

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

$S_R = 55.11$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

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

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

$V_{OA} = 1048$

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

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

$S_O = 71.12$ mi/h

C. Average Speed for Off-Ramp Junction

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

$S_{avg} = 58.7$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 64.9$ mi/h

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

$S = 58.7$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $\quad Density_R = 24.3$ pc/mi/ln

B. Density in Outer Lanes

$Density_O := \frac{V_{OA}}{S_O}$ $\quad Density_O = 14.7$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 21.1$ pc/mi/ln

D. Level of Service

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

$LOS(Density) = "C"$

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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 3418.3$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 686$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2732.3$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 162.692$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 14$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 148.692$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2881$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.1611$$

**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.*

18. Basic

**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).*

Input Values

Traffic

$FwyVol := 2881 \quad PHF := 0.95$

$f_p := 1 \quad FFS := 65 \quad S_{prev} := 58.7$

$\%Trucks_F := 5.1611 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0516$$

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

$L_{seg} := 1500$ ft $\quad L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1500 \text{ ft}$$

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9748$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1037 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$$S_{avg} = 65.0$$

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 64.4 \ \text{mi/h}$$

$$S := \begin{array}{|l} S_{avg} \ \ \text{if} \ \ S_{avg} \le S_{max} \\ S_{max} \ \ \text{if} \ \ S_{avg} > S_{max} \end{array} \qquad S = 64.4 \ \text{mi/h}$$

Density (using Eq. 23-4)

$$D := \frac{v_p}{S} \qquad D = 16.1 \ \text{pc/mi/ln}$$

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$$FwyVolNew := FwyVol = 2881$$

$$\%Trucks_{FNew} := \%Trucks_F = 5.1611$$

**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.*

19. Weaving

**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.*

Step 1. Data Inputs

OnRampVol := 455 OffRampVol := 300 SegInputVol := 2881 Int_Density := 0.87 int/mi

OnRamp%HV := 2 OffRamp%HV := 2 SegInput%HV := 5.1611

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

FFS := 65 mi/h S_{prev} := 64.4 mi/h PHF := .95 fp := 1

L_B := 1500 ft L_{seg} := 1500 ft L_{prev} := 1500 ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1500 \text{ ft}$$

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 3110.89 \qquad OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 318.9474$$

$$OnRampVolAdj := \frac{OnRampVol}{PHF \cdot f\_HV\_RF \cdot fp} = 483.7368$$

**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*

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

$f\_HV = 0.9863$

B. Volumes for Weaving Segments

$v\_RR := .05 \cdot OnRampVolAdj = 24.1868$ veh/h ** Freeplan assumes the v_RR is 5% of the total On-Ramp volume.*

$v\_FR := OffRampVolAdj - v\_RR = 294.7605$ veh/h

$v\_RF := .95 \cdot OnRampVolAdj = 459.55$ veh/h

$v\_FF := SegInputVolAdj - v\_FR = 2816.13$ veh/h

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 3.5946 \times 10^{3}$ veh/h

C. Weaving Demand Flow Rate

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

$WeavingFlowRate := WeavingDemand(N\_WL)$

$WeavingFlowRate = 754$ pc/h

D. Non-Weaving Demand Flow Rate

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

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$NonWeavingFlowRate = 2840$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$TotalFlowRate = 3595$ pc/h

F. Volume Ratio

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

$VR = 0.2098$

Step 3. Determine the Maximum Weaving Length

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

$MaximumLength = 4637$ ft $Ls := L_B \cdot .77 = 1155$

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

Step 4. Determine the Capacity of Weaving Segment

A. Weaving segment capacity determined by density

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

$C\_IWL = 2084$ pc/h/ln C_IWL is the capacity per lane under equivalent ideal conditions

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

$Cw1 = 8220$ veh/h Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

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

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

$C\_IW := C\_IW(N\_WL)$ $C\_IW = 11437$ pc/h C_IW is the capacity of the weaving segment under ideal conditions

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

$Cw2 = 11280$ veh/h Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

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

$WeavingCapacity = 8220$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$VolumeToCapacity = 0.4313$

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

Step 5. Determine Configuration Characteristics

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

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

$LC\_MIN = 754$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

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

$LaneChangingWeaving = 1055$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

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

$I\_NW = 285$ Non Weaving Vehicle Index

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

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

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

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

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

$LaneChangingNonWeaving = 441$ lc/h

C. Total Lane-Changing Rate

$$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$$

$TotalLaneChanging = 1496$ lc/h

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

A. Average Speed of Weaving Vehicles

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

$$WeavingIntensityFactor = 0.2772$$

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

$$AverageWeavingSpeed = 54.15 \quad mi/h$$

B. Average Speed of Non-Weaving Vehicles

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

$$AverageNonWeavingSpeed = 55.26 \quad mi/h$$

C. Average Speed of All Vehicles

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

$$AverageSpeed = 55.02 \quad mi/h$$

D. Maximum Achievable Speed

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

$$S := \begin{cases} AverageSpeed & \text{if } AverageSpeed \le S_{max} \\ S_{max} & \text{if } AverageSpeed > S_{max} \end{cases} \qquad S = 55.0 \quad mi/h$$

Step 8. Determine the Level of Service

$$Density := \frac{\left(\frac{TotalFlowRate}{NumLanes}\right)}{AverageSpeed} \qquad Density = 16.3 \quad pc/mi/ln$$

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

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

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

$FwyVolNew := SegInputVol + (OnRampVol - v\_RR) - (OffRampVol - v\_RR) = 3036$

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

$\%Trucks_{FNew} = 5$

**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 SegInput%HV and FwyVolNew is the input value for SegInputVol.*

20. Basic

Input Values

**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).*

Traffic

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

$f_p := 1 \quad FFS := 65 \quad S_{prev} := 55.0$

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

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

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

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

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$ $\quad L_{midpnts} = 3390$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

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

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

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

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

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

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

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

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

$S_{avg} = 65.0$

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

$S_{max} = 65.0$ mi/h

$$S := \begin{array}{|l} S_{avg} \;\; \text{if} \;\; S_{avg} \le S_{max} \\ S_{max} \;\; \text{if} \;\; S_{avg} > S_{max} \end{array}$$

$S = 65.0$ mi/h

Density (using Eq. 23-4)

$$D := \frac{v_p}{S}$$

$D = 16.8$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

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.*

21. Off-Ramp

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 $RampVol := 400$ 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

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$$

$L_{midpnts} = 3390$ 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

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

$L_{up} := 8280$ ft $L_{down} := 1000$ ft

$VolumeUp := 300$ 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

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3276 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 425 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 319 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 744 \text{ pc/h}$$

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 2797 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 838 \text{ ft}$$

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

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.659$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.613$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.639$$

$P_{FD}(Numlanes) :=$

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

$$P_{FD} := P_{FD}(NumLanes) \qquad P_{FD} = 0.659$$

C. Estimating Flow in Lanes 1 and 2

$$V_{12} := V_r + (V_f - V_r) \cdot P_{FD} \qquad V_{12} = 2302 \text{ pc/h}$$

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $\quad V_3 = 973$ pc/h

Eight Lane Freeways

$V_{av34} := \dfrac{V_f - V_{12}}{2}$ $\quad V_{av34} = 487$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(NumLanes)$ $\quad V_{12} = 2302$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

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

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

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

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

$CapacityRampRoadway = 2000$

$V_f = 3276$ 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

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

$S_R = 55.77$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

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

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

$V_{OA} = 973$

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

$S_O := S_O(V_{OA})$ $S_O = 71.30$ mi/h

C. Average Speed for Off-Ramp Junction

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

$S_{avg} = 59.63$ 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

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

$S = 59.6$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $\quad Density_R = 20$ pc/mi/ln

B. Density in Outer Lanes

$$Density_O := \frac{V_{OA}}{S_O}$$ $\quad Density_O = 13.6$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 17.9$ pc/mi/ln

D. Level of Service

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

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

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

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

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 392$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2492.2$$

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

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 8$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 143.8$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2636$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.4552$$

**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.*

22. Basic

Input Values

**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).*

Traffic

$FwyVol := 2636 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.6$

$\%Trucks_F := 5.4552 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0546$$

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.861$

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

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

$L_{seg} := 1000$ ft $\quad L_{prev} := 1500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$$

$L_{midpnts} = 1250$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9734$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 950.1 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

$$S_{avg} := \begin{cases} out \leftarrow Eqn1 & \text{if } FFS = 75 \wedge v_p > 1000 \\ out \leftarrow Eqn2 & \text{if } FFS = 70 \wedge v_p > 1200 \\ out \leftarrow Eqn3 & \text{if } FFS = 65 \wedge v_p > 1400 \\ out \leftarrow Eqn4 & \text{if } FFS = 60 \wedge v_p > 1600 \\ out \leftarrow Eqn5 & \text{if } FFS = 55 \wedge v_p > 1800 \\ out \leftarrow FFS & \end{cases}$$

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 64.3$ mi/h

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

$S = 64.3$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 14.8$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

$$LOS(D) := \begin{cases} out \leftarrow \text{"F"} & \text{if } D > 45 \\ out \leftarrow \text{"E"} & \text{if } 45 \ge D > 35 \\ out \leftarrow \text{"D"} & \text{if } 35 \ge D > 26 \\ out \leftarrow \text{"C"} & \text{if } 26 \ge D > 18 \\ out \leftarrow \text{"B"} & \text{if } 18 \ge D > 11 \\ out \leftarrow \text{"A"} & \text{if } 11 \ge D \\ out & \end{cases}$$

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2636$

$\%Trucks_{FNew} := \%Trucks_F = 5.4552$

**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.*

23. On-Ramp

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

$FwyVol := 2636$ veh/h $RampVol := 700$ veh/h

$\%Trucks_F := 5.4552$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ 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

$L_{seg} := 300$ ft $L_{prev} := 1000$ ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$ $L_{midpnts} = 650$ ft Distance from midpoints of upstream and subject segments

$L_A := 500$ 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

$L_{up} := 1000$ ft $L_{down} := 1800$ ft

$VolumeUp := 400$ veh/h Volume on adjacent upstream ramp

$VolumeDown := 500$ veh/h Volume on adjacent downstream ramp

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} = 0.973 \qquad f\_HV_F = 0.973$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 2850 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 744 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 425 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 532 \text{ pc/h}$$

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

$L_{EQup} := 0.214(V_f + V_r) + 0.444 \cdot L_A + 52.32 \cdot S_{FR} - 2403$ $L_{EQup} = 681$ ft

$L_{EQdown} := \frac{V_d}{0.1096 + 0.000107 \cdot L_A}$ $L_{EQdown} = 3259$ ft

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

$Eqn1 := 0.5775 + 0.000028 \cdot L_A$ $Eqn1 = 0.592$

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $Eqn2 = 0.612$

$Eqn3 := 0.5487 + 0.2628 \cdot \frac{V_d}{L_{down}}$ $Eqn3 = 0.626$

$$P_{FM}(Numlanes) := \begin{array}{|l} out \leftarrow 1.00 \text{ if } NumLanes = 2 \\ out \leftarrow Eqn1 \text{ if } AdjUp \neq 2 \wedge AdjDn \neq 2 \wedge NumLanes = 3 \\ out \leftarrow Eqn3 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn2 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge NumLanes = 3 \\ out \leftarrow Eqn3 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn2 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\ out \leftarrow \max(Eqn1, Eqn2) \text{ 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) \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\ out \leftarrow Eqn1 \text{ 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) \text{ 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}} \text{ if } \left(\frac{V_f}{S_{FR}} \leq 72\right) \wedge (NumLanes = 4) \\ out \leftarrow 0.2178 - 0.0000125 \cdot V_r \text{ if } \left(\frac{V_f}{S_{FR}} > 72\right) \wedge (NumLanes = 4) \end{array}$$

$P_{FM} := P_{FM}(NumLanes)$ $P_{FM} = 0.626$

C. Estimating Flow in Lanes 1 and 2

$V_{12} := V_f \cdot P_{FM}$ $V_{12} = 1785$ pc/h

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $V_3 = 1065$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 533$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := \text{V12a}(\text{NumLanes})$ $V_{12} = 1785$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

$V_{R12} := V_{12} + V_r$ $V_{R12} = 2529$ 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

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

CapacityRampRoadway = 2000

$V_{FO} := V_f + V_r$ $V_{FO} = 3595$ 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

$$S_R := FFS - (FFS - 42)\cdot\left[0.321 + 0.0039\exp\left(\frac{V_{R12}}{1000}\right) - 0.002\cdot\left(L_A\frac{S_{FR}}{1000}\right)\right]$$ $S_R = 57.41$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{No}$$ $V_{OA} = 1065$

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

$S_O := S_O(V_{OA})$ $S_O = 62.97$ mi/h

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)}$$ $S_{avg} = 58.95$ mi/h

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev})\cdot e^{(-0.00162\cdot L_{midpnts})}$$ $S_{max} = 64.8$ mi/h

$$S := \begin{cases} S_{avg} & \text{if } S_{avg} \le S_{max} \\ S_{max} & \text{if } S_{avg} > S_{max} \end{cases}$$ $S = 59.0$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

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

$Density_R = 21.7$ pc/mi/ln

B. Density in Outer Lanes

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

$Density_O = 16.9$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 20.1$ pc/mi/ln

D. Level of Service

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

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

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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 2492.2$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 686$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} + RampVol_{Cars} = 3178.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 143.799$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 14$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} + RampVol_{Trucks} = 157.799$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 3336$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 4.7302$$

**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.*

24. RampOverlap

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

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

Off-Ramp 25 Speed and Density

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

Ramp Overlap 24 Speed and Density

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

25. Off-Ramp

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

$FwyVol := 3336$ veh/h $RampVol := 500$ veh/h

$\%Trucks_F := 4.7302$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 59.0$ 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

$L_{seg} := 300$ ft $L_{prev} := 1200$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 750 \text{ ft}$$

Distance from midpoints of upstream and subject segments

$L_D := 350$ ft Total length of Deceleration Lane

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

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

$L_{up} := 1800$ ft $L_{down} := 1000$ ft

$VolumeUp := 700$ veh/h Volume on adjacent upstream ramp

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

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} \qquad f\_HV_F = 0.977$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3595 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 532 \text{ pc/h}$$

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

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

$$L_{EQup} := \frac{V_u}{0.071 + 0.000023 \cdot V_f - 0.000076 \cdot V_r} \qquad L_{EQup} = 6570 \text{ ft}$$

$$L_{EQdown} := \frac{V_d}{1.15 - 0.000032 \cdot V_f - 0.000369 \cdot V_r} \qquad L_{EQdown} = 887 \text{ ft}$$

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

$$Eqn1 := 0.760 - 0.000025 \cdot V_f - 0.000046 \cdot V_r \qquad Eqn1 = 0.646$$

$$Eqn2 := 0.717 - 0.000039 \cdot V_f + 0.604 \cdot \frac{V_u}{L_{up}} \qquad Eqn2 = 0.827$$

$$Eqn3 := 0.616 - 0.000021 \cdot V_f + 0.124 \cdot \frac{V_d}{L_{down}} \qquad Eqn3 = 0.633$$

$P_{FD}(Numlanes) :=$

$$
\begin{aligned}
&out \leftarrow 1.00 \quad \text{if} \quad NumLanes = 2\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 0 \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 1 \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3\\
&out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 0 \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3\\
&out \leftarrow Eqn2 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3\\
&out \leftarrow \max(Eqn2, Eqn3) \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow \max(Eqn2, Eqn1) \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow \max(Eqn3, Eqn1) \quad \text{if} \quad AdjUp = 1 \wedge AdjDn = 2 \wedge L_{up} \geq L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 1 \wedge NumLanes = 3\\
&out \leftarrow Eqn1 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow Eqn3 \quad \text{if} \quad AdjUp = 2 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3\\
&out \leftarrow 0.436 \quad \text{if} \quad NumLanes = 4
\end{aligned}
$$

$$P_{FD} := P_{FD}(NumLanes) \qquad P_{FD} = 0.827$$

C. Estimating Flow in Lanes 1 and 2

$$V_{12} := V_r + (V_f - V_r) \cdot P_{FD} \qquad V_{12} = 3063 \text{ pc/h}$$

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways *Eight Lane Freeways*

$V_3 := V_f - V_{12}$ $V_3 = 531$ pc/h $V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 266$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(NumLanes)$ $V_{12} = 3063$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

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

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

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

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

$CapacityRampRoadway = 2000$

$V_f = 3595$ 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

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

$S_R = 55.55$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$N_o := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases} \qquad V_{OA} := \frac{V_f - V_{12}}{N_o} \qquad V_{OA} = 531$$

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

$S_O := S_O(V_{OA})$ $S_O = 71.30$ mi/h

C. Average Speed for Off-Ramp Junction

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

$S_{avg} = 57.43$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 63.2$ mi/h

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

$S = 57.4$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in Off-Ramp Influence Area

$Density_R := 4.252 + 0.0086 \cdot V_{12} - 0.009 \cdot L_D$ $Density_R = 27.4$ pc/mi/ln

B. Density in Outer Lanes

$Density_O := \frac{V_{OA}}{S_O}$ $Density_O = 7.5$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 20.8$ pc/mi/ln

D. Level of Service

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

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

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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 3178.2$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 490$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} - RampVol_{Cars} = 2688.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 157.799$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 10$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} - RampVol_{Trucks} = 147.799$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 2836$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 5.2115$$

**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.*

26. Basic

Input Values

**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).*

Traffic

$FwyVol := 2836 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 57.4$

$\%Trucks_F := 5.2115 \quad P_R := 0$

$P_T := \frac{\%Trucks_F}{100} = 0.0521$

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.691085$

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

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

$L_{seg} := 1000$ ft $\quad L_{prev} := 300$ ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 650$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9746$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1021 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

$S_{max} := FFS - \left(FFS - S_{prev}\right) \cdot e^{\left(-0.00162 \cdot L_{midpnts}\right)}$ $S_{max} = 62.3$ mi/h

$$S := \begin{array}{|l} S_{avg} \ \text{ if } \ S_{avg} \le S_{max} \\ S_{max} \ \text{ if } \ S_{avg} > S_{max} \end{array}$$

$S = 62.3$ mi/h

Density (using Eq. 23-4)

$D := \dfrac{v_p}{S}$ $D = 16.4$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 2836$

$\%Trucks_{FNew} := \%Trucks_F = 5.2115$

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

27. On-Ramp

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

$FwyVol := 2836$ veh/h $RampVol := 700$ veh/h

$\%Trucks_F := 5.2115$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 64.0$ 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 $L_{prev} := 1000$ ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$ $L_{midpnts} = 1250$ 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

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

$L_{up} := 1000$ ft $L_{down} := 6780$ ft

$VolumeUp := 500$ veh/h   Volume on adjacent upstream ramp

$VolumeDown := 600$ veh/h   Volume on adjacent downstream ramp

B. Heavy Vehicle Adjustments

Passenger Car Equivalents

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

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

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

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

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

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3063 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 744 \text{ pc/h}$$

$$V_u := \frac{VolumeUp}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_u = 532 \text{ pc/h} \qquad V_d := \frac{VolumeDown}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_d = 638 \text{ pc/h}$$

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

$L_{EQup} := 0.214(V_f + V_r) + 0.444 \cdot L_A + 52.32 \cdot S_{FR} - 2403$ $L_{EQup} = 949$ ft

$L_{EQdown} := \frac{V_d}{0.1096 + 0.000107 \cdot L_A}$ $L_{EQdown} = 2945$ ft

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

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

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $Eqn2 = 0.609$

$Eqn3 := 0.5487 + 0.2628 \cdot \frac{V_d}{L_{down}}$ $Eqn3 = 0.573$

$P_{FM}(Numlanes) :=$

$out \leftarrow 1.00$ 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

$V_{12} := V_f \cdot P_{FM}$ $V_{12} = 1855$ pc/h

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $\quad V_3 = 1208$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $\quad V_{av34} = 604$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := V12a(NumLanes)$ $\quad V_{12} = 1855$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

$V_{R12} := V_{12} + V_r$ $V_{R12} = 2599$ pc/h Flow entering the ramp influence area

CapUpFreewaySegment(NumLanes , FFS) :=

out ← 4800	if	FFS ≥ 70 ∧ NumLanes = 2
out ← 4700	if	FFS = 65 ∧ NumLanes = 2
out ← 4600	if	FFS = 60 ∧ NumLanes = 2
out ← 4600	if	FFS = 55 ∧ NumLanes = 2
out ← 7200	if	FFS = 70 ∧ NumLanes = 3
out ← 7050	if	FFS = 65 ∧ NumLanes = 3
out ← 6900	if	FFS = 60 ∧ NumLanes = 3
out ← 6750	if	FFS = 55 ∧ NumLanes = 3
out ← 9600	if	FFS = 70 ∧ NumLanes = 4
out ← 9400	if	FFS = 65 ∧ NumLanes = 4
out ← 9200	if	FFS = 60 ∧ NumLanes = 4
out ← 9000	if	FFS = 55 ∧ NumLanes = 4
out ← 2400·NumLanes	if	FFS = 70 ∧ NumLanes > 4
out ← 2350·NumLanes	if	FFS = 65 ∧ NumLanes > 4
out ← 2300·NumLanes	if	FFS = 60 ∧ NumLanes > 4
out ← 2250·NumLanes	if	FFS = 55 ∧ NumLanes > 4

CapUpFreewaySegment(NumLanes , FFS) = 7050 Capacity of Ramp Freeway Junction

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

CapacityRampRoadway :=

out ← 2200	if	$(NRamp = 1) \wedge (S_{FR} > 50)$
out ← 2100	if	$(NRamp = 1) \wedge (40 < S_{FR} \le 50)$
out ← 2000	if	$(NRamp = 1) \wedge (30 < S_{FR} \le 40)$
out ← 1900	if	$(NRamp = 1) \wedge (20 \le S_{FR} \le 30)$
out ← 1800	if	$(NRamp = 1) \wedge (20 > S_{FR})$
out ← 4400	if	$(NRamp = 2) \wedge (S_{FR} > 50)$
out ← 4200	if	$(NRamp = 2) \wedge (40 < S_{FR} \le 50)$
out ← 4000	if	$(NRamp = 2) \wedge (30 < S_{FR} \le 40)$
out ← 3800	if	$(NRamp = 2) \wedge (20 \le S_{FR} \le 30)$
out ← 3600	if	$(NRamp = 2) \wedge (20 > S_{FR})$

$CapacityRampRoadway = 2000$

$V_{FO} := V_f + V_r$ $V_{FO} = 3807$ 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

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

$S_R = 58.25$ mi/h

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases}$$

$$V_{OA} := \frac{V_f - V_{12}}{No}$$

$V_{OA} = 1208$

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

$S_O := S_O(V_{OA})$ $S_O = 62.45$ mi/h

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)}$$

$S_{avg} = 59.52$ mi/h

D. Maximum Achievable Speed

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

$S_{max} = 64.9$ mi/h

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

$S = 59.5$ mi/h

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

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

$Density_R = 19.1$ pc/mi/ln

B. Density in Outer Lanes

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

$Density_O = 19.3$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 19.2$ 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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 2688.2$$

$$RampVol_{Cars} := RampVol \cdot \left(1 - \frac{\%Trucks_R}{100}\right) = 686$$

$$FwyVol_{CarsNew} := FwyVol_{Cars} + RampVol_{Cars} = 3374.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 147.798$$

$$RampVol_{Trucks} := RampVol \cdot \left(\frac{\%Trucks_R}{100}\right) = 14$$

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} + RampVol_{Trucks} = 161.798$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 3536$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 4.5757$$

**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.*

28. Basic

Input Values

**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).*

Traffic

$FwyVol := 3536 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 59.5$

$\%Trucks_F := 4.5757 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0458$$

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.691085$

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

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

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

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

Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9776$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1269.1 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$ $S_{max} = 65.0$ mi/h

$$S := \left| \begin{array}{l} S_{avg} \ \text{ if } \ S_{avg} \le S_{max} \\ S_{max} \ \text{ if } \ S_{avg} > S_{max} \end{array} \right.$$ $S = 65.0$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 19.5$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 3536$

$\%Trucks_{FNew} := \%Trucks_F = 4.5757$

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

29. Weaving

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 := 600 OffRampVol := 455 SegInputVol := 3536 Int_Density := 0.87 int/mi

OnRamp%HV := 2 OffRamp%HV := 2 SegInput%HV := 4.5757

FFS := 65 mi/h S_{prev} := 65.0 mi/h PHF := .95 fp := 1.00

L_B := 4500 ft L_{seg} := 4500 ft L_{prev} := 5280 ft

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

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 4890 \text{ ft}$$

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 3807.261 \qquad OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 483.737$$

$$OnRampVolAdj := \frac{OnRampVol}{PHF \cdot f\_HV\_RF \cdot fp} = 637.895$$

**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*

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

$f\_HV = 0.987$

B. Volumes for Weaving Segments

$v\_RR := .05 \cdot OnRampVolAdj = 31.895$ veh/h

** Freeplan assumes the v_RR is 5% of the total On-Ramp volume.*

$v\_FR := OffRampVolAdj - v\_RR = 451.842$ veh/h

$v\_RF := .95 \cdot OnRampVolAdj = 606$ veh/h

$v\_FF := SegInputVolAdj - v\_FR = 3355.42$ veh/h

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 4.445 \times 10^3$ veh/h

C. Weaving Demand Flow Rate

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

$WeavingFlowRate := WeavingDemand(N\_WL)$

$WeavingFlowRate = 1058$ pc/h

D. Non-Weaving Demand Flow Rate

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

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$NonWeavingFlowRate = 3387$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$TotalFlowRate = 4445$ pc/h

F. Volume Ratio

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

$VR = 0.238$

Step 3. Determine the Maximum Weaving Length

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

$MaximumLength = 4928$ ft $\quad Ls := L_B \cdot .77 = 3465$

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

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

$C\_IWL = 2238$ pc/h/ln — C_IWL is the capacity per lane under equivalent ideal conditions

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

$Cw1 = 8836$ veh/h — Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

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

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

$C\_IW := C\_IW\left(N\_WL\right) \quad C\_IW = 10085$ pc/h — C_IW is the capacity of the weaving segment under ideal conditions

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

$Cw2 = 9954$ veh/h — Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

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

$WeavingCapacity = 8836$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$VolumeToCapacity = 0.497$

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

Step 5. Determine Configuration Characteristics

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

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

$LC\_MIN = 1058$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

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

$LaneChangingWeaving = 1637$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

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

$I\_NW = 1021$ Non Weaving Vehicle Index

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

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

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

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

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

$LaneChangingNonWeaving = 1805$ lc/h

C. Total Lane-Changing Rate

$$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$$

$TotalLaneChanging = 3442$ lc/h

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

A. Average Speed of Weaving Vehicles

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

$$WeavingIntensityFactor = 0.225$$

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

$$AverageWeavingSpeed = 55.82 \quad \text{mi/h}$$

B. Average Speed of Non-Weaving Vehicles

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

$$AverageNonWeavingSpeed = 52.05 \quad \text{mi/h}$$

C. Average Speed of All Vehicles

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

$$AverageSpeed = 52.9 \quad \text{mi/h}$$

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 65.0 \quad \text{mi/h}$$

$$S := \begin{cases} AverageSpeed & \text{if } AverageSpeed \le S_{max} \\ S_{max} & \text{if } AverageSpeed > S_{max} \end{cases} \qquad S = 52.9 \quad \text{mi/h}$$

Step 8. Determine the Level of Service

$$Density := \frac{\left(\frac{TotalFlowRate}{NumLanes}\right)}{AverageSpeed} \qquad Density = 21 \quad \text{pc/mi/ln}$$

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

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

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

$$FwyVolNew := SegInputVol + (OnRampVol - v\_RR) - (OffRampVol - v\_RR) = 3681$$

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

$\%Trucks_{FNew} = 4.474$

***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.**

30. Basic

Input Values

**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).*

Traffic

$FwyVol := 3681 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 52.9$

$\%Trucks_F := 4.4742 \quad P_R := 0$

$$P_T := \frac{\%Trucks_F}{100} = 0.0447$$

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.861$

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

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

$L_{seg} := 1140$ ft $\quad L_{prev} := 4500$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$$

$L_{midpnts} = 2820$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

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

$E_R(Terrain) = 1.2 \quad E_R := E_R(Terrain)$

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

$f_{HV} = 0.9781$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p}$$

$v_p = 1320.5$ pc/h/ln

Determine S

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

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

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

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

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

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

$S_{avg} = 65.0$

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

$$S := \begin{array}{|l} S_{avg} \ \ \text{if } S_{avg} \le S_{max} \\ S_{max} \ \ \text{if } S_{avg} > S_{max} \end{array}$$

$S = 64.9$ mi/h

Density (using Eq. 23-4)

$D := \frac{v_p}{S}$ $D = 20.4$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 3681$

$\%Trucks_{FNew} := \%Trucks_F = 4.4742$

**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.*

31. Weaving

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 := 455 OffRampVol := 455 SegInputVol := 3681 Int_Density := 0.861 int/mi

OnRamp%HV := 2 OffRamp%HV := 2 SegInput%HV := 4.4742

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

FFS := 65 mi/h S_{prev} := 64.9 mi/h PHF := .95 fp := 1

L_B := 2000 ft L_{seg} := 2000 ft L_{prev} := 1140 ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1570 \text{ ft}$$

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.*

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

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

$$SegInputVolAdj := \frac{SegInputVol}{PHF \cdot f\_HV\_FF \cdot fp} = 3961.419 \qquad OffRampVolAdj := \frac{OffRampVol}{PHF \cdot f\_HV\_FR \cdot fp} = 483.7368$$

$$OnRampVolAdj := \frac{OnRampVol}{PHF \cdot f\_HV\_RF \cdot fp} = 483.7368$$

**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*

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

$f\_HV = 0.9871$

B. Volumes for Weaving Segments

$v\_RR := .05 \cdot OnRampVolAdj = 24.1868$ veh/h ** Freeplan assumes the v_RR is 5% of the total On-Ramp volume.*

$v\_FR := OffRampVolAdj - v\_RR = 459.55$ veh/h

$v\_RF := .95 \cdot OnRampVolAdj = 459.55$ veh/h

$v\_FF := SegInputVolAdj - v\_FR = 3501.87$ veh/h

$v\_Total := v\_FF + v\_RF + v\_FR + v\_RR = 4.4452 \times 10^{3}$ veh/h

C. Weaving Demand Flow Rate

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

$WeavingFlowRate := WeavingDemand(N\_WL)$

$WeavingFlowRate = 919$ pc/h

D. Non-Weaving Demand Flow Rate

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

$NonWeavingFlowRate := NonWeavingDemand(N\_WL)$

$NonWeavingFlowRate = 3526$ pc/h

E. Total Demand Flow Rate

$TotalFlowRate := WeavingFlowRate + NonWeavingFlowRate$

$TotalFlowRate = 4445$ pc/h

F. Volume Ratio

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

$VR = 0.2068$

Step 3. Determine the Maximum Weaving Length

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

$MaximumLength = 4605$ ft $\quad Ls := L_B \cdot .77 = 1540$

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

Step 4. Determine the Capacity of Weaving Segment

A. Weaving segment capacity determined by density

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

$C\_IWL = 2115$ pc/h/ln C_IWL is the capacity per lane under equivalent ideal conditions

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

$Cw1 = 8353$ veh/h Cw1 is the density based capacity of weaving segment under prevailing conditions

B. Weaving segment capacity determined by weaving demand flows

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

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.

$C\_IW := C\_IW(N\_WL)$ $\quad C\_IW = 11607$ pc/h C_IW is the capacity of the weaving segment under ideal conditions

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

$Cw2 = 11458$ veh/h Cw2 is the flow based capacity of weaving segment under prevailing conditions

C. Final Capacity of Weaving Segment

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

$WeavingCapacity = 8353$ veh/h

D. Volume to Capacity (v/c) Ratio

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

$VolumeToCapacity = 0.5253$

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

Step 5. Determine Configuration Characteristics

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

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

$LC\_MIN = 919$ lc/h Minimum Lane Changes

Step 6. Determine Lane-Changing Rates

A. Lane-Changing Rate for Weaving Vehicles

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

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

$LaneChangingWeaving = 1280$ lc/h

B. Lane-Changing Rate for Non-Weaving Vehicles

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

$I\_NW = 468$ Non Weaving Vehicle Index

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

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

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

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

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

$LaneChangingNonWeaving = 791$ lc/h

C. Total Lane-Changing Rate

$$TotalLaneChanging := LaneChangingWeaving + LaneChangingNonWeaving$$

$TotalLaneChanging = 2071$ lc/h

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

A. Average Speed of Weaving Vehicles

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

$$WeavingIntensityFactor = 0.2855$$

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

$$AverageWeavingSpeed = 53.9 \quad \text{mi/h}$$

B. Average Speed of Non-Weaving Vehicles

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

$$AverageNonWeavingSpeed = 53.05 \quad \text{mi/h}$$

C. Average Speed of All Vehicles

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

$$AverageSpeed = 53.22 \quad \text{mi/h}$$

D. Maximum Achievable Speed

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})} \qquad S_{max} = 65.0 \quad \text{mi/h}$$

$$S := \begin{cases} AverageSpeed & \text{if } AverageSpeed \le S_{max} \\ S_{max} & \text{if } AverageSpeed > S_{max} \end{cases} \qquad S = 53.2 \quad \text{mi/h}$$

Step 8. Determine the Level of Service

$$Density := \frac{\left(\frac{TotalFlowRate}{NumLanes}\right)}{AverageSpeed} \qquad Density = 20.9 \quad \text{pc/mi/ln}$$

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

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

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

$FwyVolNew := SegInputVol + (OnRampVol - v\_RR) - (OffRampVol - v\_RR) = 3681$

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

$\%Trucks_{FNew} = 4.474$

**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.*

32. Basic

Input Values

**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).*

Traffic

$FwyVol := 3681 \quad PHF := 0.95$

$f_p := 1.0 \quad FFS := 65 \quad S_{prev} := 53.2$

$\%Trucks_F := 4.4742 \quad P_R := 0$

$P_T := \frac{\%Trucks_F}{100} = 0.0447$

Roadway

$N := 3 \quad LaneWidth := 12 \quad LatClear := 6 \quad IntDens := 0.861$

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

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

$L_{seg} := 1140$ ft $\quad L_{prev} := 2000$ ft

$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2}$

$L_{midpnts} = 1570$ ft Distance from midpoints of upstream and subject segments

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

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

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

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

$$f_{HV} := \frac{1}{1 + P_T \cdot (E_T - 1) + P_R \cdot (E_R - 1)} \qquad f_{HV} = 0.9781$$

Find v_p (using Eq. 23-2)

$$v_p := \frac{FwyVol}{PHF \cdot N \cdot f_{HV} \cdot f_p} \qquad v_p = 1320.5 \text{ pc/h/ln}$$

Determine S

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

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

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

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

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

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

$$S_{avg} = 65.0$$

$$S_{max} := FFS - (FFS - S_{prev}) \cdot e^{(-0.00162 \cdot L_{midpnts})}$$ $S_{max} = 64.1$ mi/h

$$S := \begin{array}{|l} S_{avg} \ \text{ if } \ S_{avg} \le S_{max} \\ S_{max} \ \text{ if } \ S_{avg} > S_{max} \end{array}$$ $S = 64.1$ mi/h

Density (using Eq. 23-4)

$$D := \frac{v_p}{S}$$ $D = 20.6$ pc/mi/ln

Determine level of service (using Exhibit 23-2)

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

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

Determine Input Vol and %HV for Next Downstream Segment

$FwyVolNew := FwyVol = 3681$

$\%Trucks_{FNew} := \%Trucks_F = 4.4742$

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

33. On-Ramp

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

$FwyVol := 3681$ veh/h $RampVol := 455$ veh/h

$\%Trucks_F := 4.4742$ $\%RV_F := 0$ $PHF := 0.95$ $f_p := 1$ $FFS := 65$ mi/h

$\%Trucks_R := 2$ $\%RV_R := 0$ $S_{prev} := 64.1$ 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 $L_{prev} := 1140$ ft

$$L_{midpnts} := \frac{L_{seg} + L_{prev}}{2} \qquad L_{midpnts} = 1320 \text{ ft}$$

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

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

$L_{up} := 1140$ ft $L_{down} := 6000$ 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

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

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

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

$$f\_HV_F := \frac{100}{100 + \%Trucks_F(E_T - 1) + \%RV_F(E_R - 1)} = 0.978 \qquad f\_HV_F = 0.978$$

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

C. Demand Flow Rate

$$V_f := \frac{FwyVol}{PHF \cdot f\_HV_F \cdot f_p} \qquad V_f = 3961 \text{ pc/h} \qquad V_r := \frac{RampVol}{PHF \cdot f\_HV_R \cdot f_p} \qquad V_r = 484 \text{ pc/h}$$

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

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

$L_{EQup} := 0.214(V_f + V_r) + 0.444 \cdot L_A + 52.32 \cdot S_{FR} - 2403$ $\quad L_{EQup} = 1085$ ft

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

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

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

$Eqn2 := 0.7289 - 0.0000135 \cdot (V_f + V_r) - 0.003296 \cdot S_{FR} + 0.000063 \cdot L_{up}$ $\quad Eqn2 = 0.609$

$Eqn3 := 0.5487 + 0.2628 \cdot \dfrac{V_d}{L_{down}}$ $\quad Eqn3 = 0.57$

$$P_{FM}(Numlanes) := \begin{array}{l}
out \leftarrow 1.00 \text{ if } NumLanes = 2 \\
out \leftarrow Eqn1 \text{ if } AdjUp \neq 2 \wedge AdjDn \neq 2 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 0 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 0 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 1 \wedge NumLanes = 3 \\
out \leftarrow Eqn3 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 1 \wedge AdjDn = 2 \wedge L_{down} \geq L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn2 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} < L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ if } AdjUp = 2 \wedge AdjDn = 1 \wedge L_{up} \geq L_{EQup} \wedge NumLanes = 3 \\
out \leftarrow \max(Eqn1, Eqn2) \text{ 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) \text{ if } AdjUp = 2 \wedge AdjDn = 2 \wedge L_{up} < L_{EQup} \wedge L_{down} < L_{EQdown} \wedge NumLanes = 3 \\
out \leftarrow Eqn1 \text{ 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) \text{ 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 \dfrac{L_A}{S_{FR}} \text{ if } \left(\dfrac{V_f}{S_{FR}} \leq 72\right) \wedge (NumLanes = 4) \\
out \leftarrow 0.2178 - 0.0000125 \cdot V_r \text{ if } \left(\dfrac{V_f}{S_{FR}} > 72\right) \wedge (NumLanes = 4)
\end{array}$$

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

C. Estimating Flow in Lanes 1 and 2

$V_{12} := V_f \cdot P_{FM}$ $\quad V_{12} = 2399$ pc/h

D. Checking the Reasonableness of the Lane Distribution Prediction

Six Lane Freeways

$V_3 := V_f - V_{12}$ $V_3 = 1563$ pc/h

Eight Lane Freeways

$V_{av34} := \frac{V_f - V_{12}}{2}$ $V_{av34} = 781$ pc/h

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

C. Final Flow in Lanes 1 and 2

$V_{12} := \text{V12a}(\text{NumLanes})$ $V_{12} = 2399$ pc/h

Step 3. Determine Capacity of Ramp-Freeway Junction

$V_{R12} := V_{12} + V_r$ $V_{R12} = 2882$ pc/h Flow entering the ramp influence area

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

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

MaxV12 = 4600 Maximum Desirable Flow Rate Entering Merge Influence Area

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

$CapacityRampRoadway = 2000$

$V_{FO} := V_f + V_r$ $V_{FO} = 4445$ 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

$$S_R := FFS - (FFS - 42)\cdot\left[0.321 + 0.0039\exp\left(\frac{V_{R12}}{1000}\right) - 0.002\cdot\left(L_A\frac{S_{FR}}{1000}\right)\right] \qquad S_R = 57.86 \text{ mi/h}$$

B. Average Speed in the Outer Lanes of Freeway

Average Flow in Outer Lanes

$$No := \begin{cases} out \leftarrow 1 & \text{if } NumLanes = 3 \\ out \leftarrow 2 & \text{if } NumLanes = 4 \\ out \leftarrow \infty & \text{if } NumLanes = 2 \end{cases} \qquad V_{OA} := \frac{V_f - V_{12}}{No} \qquad V_{OA} = 1563$$

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

$$S_O := S_O(V_{OA}) \qquad S_O = 61.17 \text{ mi/h}$$

C. Average Speed for On-Ramp Junction

$$S_{avg} := \frac{V_{R12} + V_{OA}\cdot No}{\left(\frac{V_{R12}}{S_R}\right) + \left(\frac{V_{OA}\cdot No}{S_O}\right)} \qquad S_{avg} = 58.98 \text{ mi/h}$$

D. Maximum Achievable Speed

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

$$S := \begin{cases} S_{avg} & \text{if } S_{avg} \le S_{max} \\ S_{max} & \text{if } S_{avg} > S_{max} \end{cases} \qquad S = 59.0 \text{ mi/h}$$

Step 5. Determine the Density and Level of Service

A. Density in On-Ramp Influence Area

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

$Density_R = 21.5$ pc/mi/ln

B. Density in Outer Lanes

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

$Density_O = 25.5$ pc/mi/ln

C. Density of Entire Cross-Section

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

$Density = 22.8$ pc/mi/ln

D. Level of Service

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

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

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

$$FwyVol_{Cars} := FwyVol \cdot \left(1 - \frac{\%Trucks_F}{100}\right) = 3516.3$$

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

$$FwyVol_{CarsNew} := FwyVol_{Cars} + RampVol_{Cars} = 3962.2$$

$$FwyVol_{Trucks} := FwyVol \cdot \frac{\%Trucks_F}{100} = 164.695$$

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

$$FwyVol_{TrucksNew} := FwyVol_{Trucks} + RampVol_{Trucks} = 173.795$$

$$FwyVolNew := FwyVol_{CarsNew} + FwyVol_{TrucksNew} = 4136$$

$$\%Trucks_{FNew} := \frac{FwyVol_{TrucksNew}}{FwyVolNew} \cdot 100 = 4.2020$$

**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.*

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

$$FacilitySpeed := \frac{\sum_{i=1}^{n} LSeg_i}{\sum_{i=1}^{n} TTSeg_i} \qquad FacilityDensity := \frac{\sum_{i=1}^{n} \left(nLDSeg_i\right)}{\sum_{i=1}^{n} \left(nLSeg_i\right)}$$

$FacilitySpeed$ *= 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

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

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

$nL_9 := n_9 \cdot L_9 = 6840$

10. Weave Segment

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

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

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

11. Basic Segment

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

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

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

12. On-Ramp Segment

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

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

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

13. Off-Ramp Segment

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

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

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

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

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

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

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

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

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

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