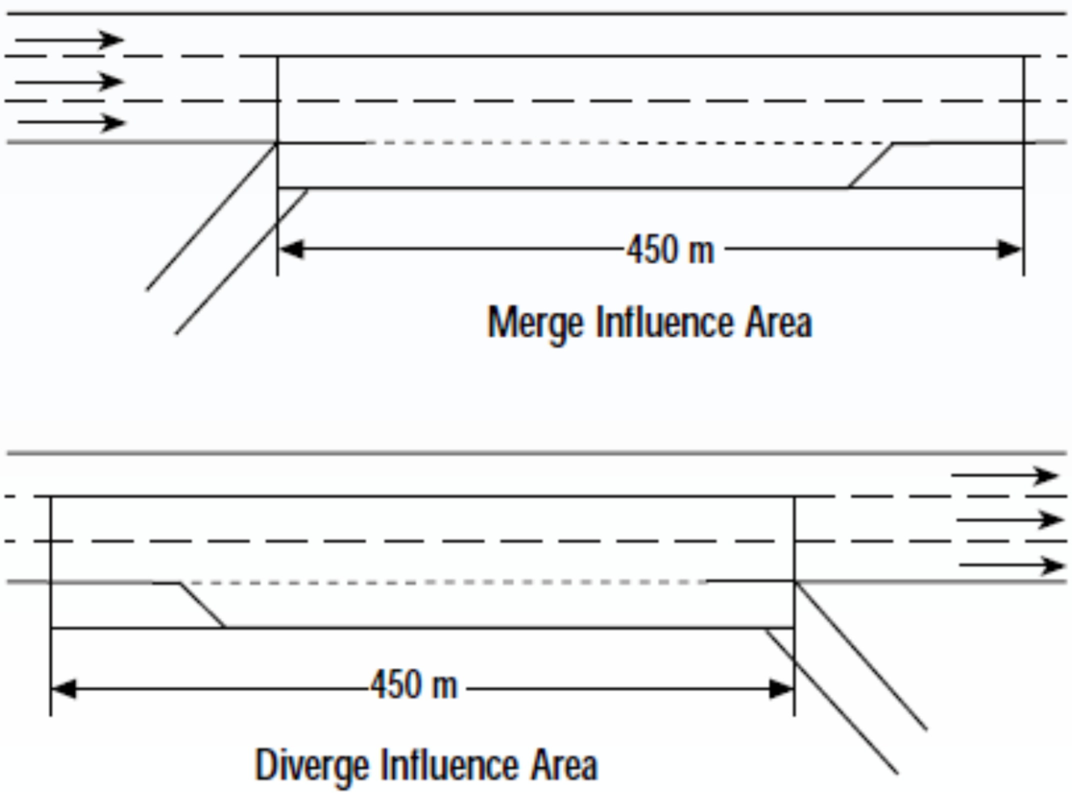
CIVE 440

Traffic Engineering and Simulation – Highways part 2

Faculty of Engineering
Department of Civil Engineering and Applied Mechanics
Fall 2016

MERGE AND DIVERGE

EXHIBIT 13-14. ON- AND OFF-RAMP INFLUENCE AREAS

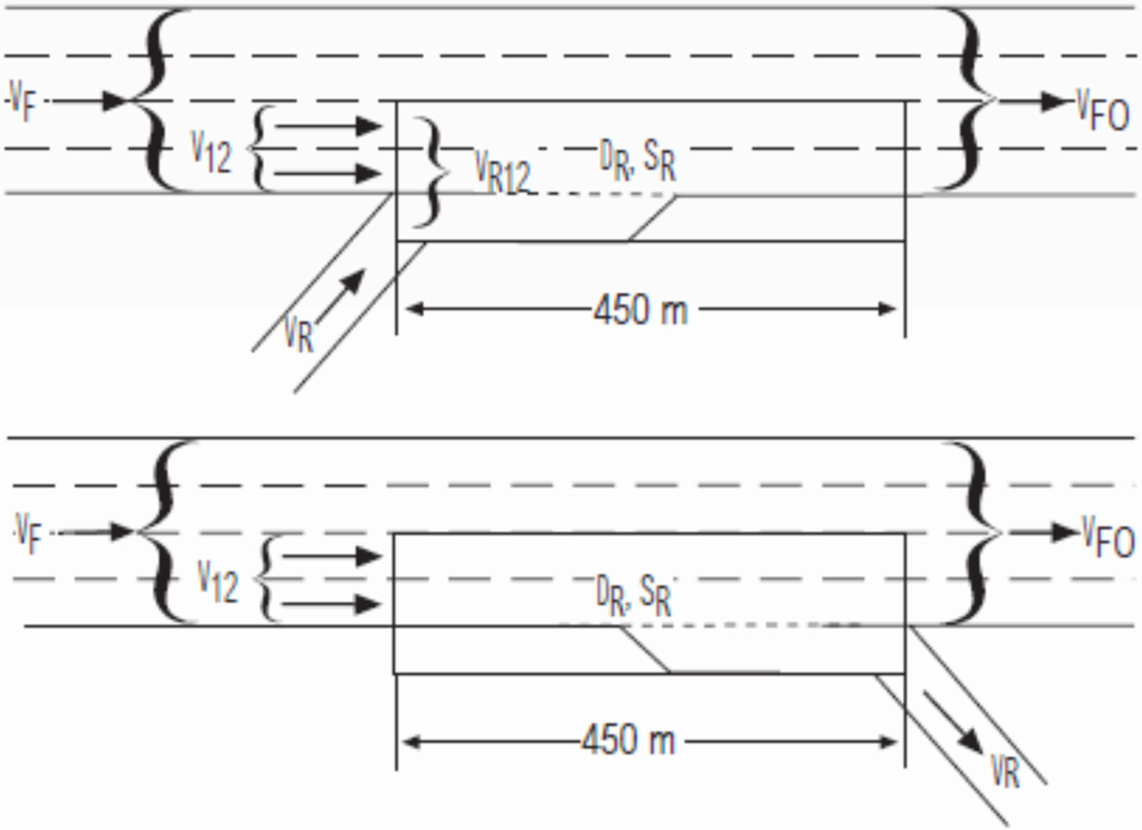


PARAMETERS

For merge and diverge, focus is on the immediate segment around the on/off ramp. Parameters:

- V_{12} – flow entering lanes 1 and 2
- V_F – Max. total flow approaching a merge/diverge area
- V_{FO} – Max. total flow leaving a merge/diverge area
- V_{R12} – Max. total flow entering the influence area for merge
- V_{12} – Max. total flow entering the influence area for diverge
- V_R – Max flow on the ramp
- D_R – Density within the ramp influence area
- S_R –Average Speed within the ramp influence area

EXHIBIT 25-2. CRITICAL RAMP JUNCTION VARIABLES



APPROACH

Steps for capacity and LOS analysis:

- First, determine flow entering lanes 1 and 2 immediately upstream of the merge influence area (V_{12}) or at the beginning of the deceleration lane at diverge from P_{FM}.
- Second, evaluate the capacity values against demand V_F, V_{FO}, V_{12}, and V_R
- Third, determine the density of flow within the ramp influence area (D_R) and the level of service based on this variable.
    - For some situations, the average speed of vehicles within the influence area (S_R) may also be estimated.

LOS criteria and demand flow conversion is as with basic and weaving highway segments.

As part of step 2, several capacity values are evaluated from Table 25-3, Table 25-7, or Table 25-14:

- Maximum total flow approaching a major diverge area on the freeway (capacity requirement for V_F)
- Maximum total flow departing from a merge or diverge area on the freeway (capacity requirement for V_{FO})
- Maximum total flow entering the ramp influence area (capacity requirement for V_{12} or V_{R12})
- Maximum flow on a ramp (capacity requirement for V_R)

EXHIBIT 25-3. APPROXIMATE CAPACITY OF RAMP ROADWAYS

Free-Flow Speed of Ramp, S_{FR} (km/h)	Capacity (pc/h)	
	Single-Lane Ramps	Two-Lane Ramps
> 80	2200	4400
> 65–80	2100	4100
> 50–65	2000	3800
≥ 30–50	1900	3500
< 30	1800	3200

EXHIBIT 25-7. CAPACITY VALUES FOR MERGE AREAS

Freeway Free-Flow Speed (km/h)	Maximum Downstream Freeway Flow, v (pc/h)				Max Desirable Flow Entering Influence Area, v_{R12} (pc/h)
	Number of Lanes in One Direction				
	2	3	4	> 4	
120	4800	7200	9600	2400/ln	4600
110	4700	7050	9400	2350/ln	4600
100	4600	6900	9200	2300/ln	4600
90	4500	6750	9000	2250/ln	4600

EXHIBIT 25-14. CAPACITY VALUES FOR DIVERGE AREAS

Freeway Free-Flow Speed (km/h)	Maximum Upstream, v_{FI} or Downstream Freeway Flow, v (pc/h)				Max Flow Entering Influence Area, v_{12} (pc/h)
	Number of Lanes in One Direction				
	2	3	4	> 4	
120	4800	7200	9600	2400/ln	4400
110	4700	7050	9400	2350/ln	4400
100	4600	6900	9200	2300/ln	4400
90	4500	6750	9000	2250/ln	4400

ON-RAMP INFLUENCE AREA FLOW

EXHIBIT 25-5. MODELS FOR PREDICTING v_{12} AT ON-RAMPS

$v_{12} = v_F * P_{FM}$		
For 4-lane freeways (2 lanes each direction)	$P_{FM} = 1.000$	
For 6-lane freeways (3 lanes each direction)	$P_{FM} = 0.5775 + 0.000092L_A$	(Equation 1)
	$P_{FM} = 0.7289 - 0.0000135\,(v_F + v_R) - 0.002048S_{FR} + 0.0002L_{up}$	(Equation 2)
	$P_{FM} = 0.5487 + 0.0801\,v_D/L_{down}$	(Equation 3)
For 8-lane freeways (4 lanes each direction)	$P_{FM} = 0.2178 - 0.000125v_R + 0.05887L_A/S_{FR}$	(Equation 4)

v_{12} = flow rate in Lanes 1 and 2 of freeway immediately upstream of merge (pc/h),
v_F = freeway demand flow rate immediately upstream of merge (pc/h),
v_R = on-ramp demand flow rate (pc/h),
v_D = demand flow rate on adjacent downstream ramp (pc/h),
P_{FM} = proportion of approaching freeway flow remaining in Lanes 1 and 2 immediately upstream of merge,

L_A = length of acceleration lane (m),
S_{FR} = free-flow speed of ramp (km/h),
L_{up} = distance to adjacent upstream ramp (m), and
L_{down} = distance to adjacent downstream ramp (m).

EXHIBIT 25-6. SELECTING EQUATIONS FOR P_{FM} FOR SIX-LANE FREEWAYS

Adjacent Upstream Ramp (Previous ramp)	Subject Ramp	Adjacent Downstream Ramp (Next ramp)	Equation(s) Used
None	On	None	Equation 1
None	On	On	Equation 1
None	On	Off	Equation 3 or 1
On	On	None	Equation 1
Off	On	None	Equation 2 or 1
On	On	On	Equation 1
On	On	Off	Equation 3 or 1
Off	On	On	Equation 2 or 1
Off	On	Off	Equation 3, 2, or 1

For six-lane highways, choice of equation in table 25-5 from criteria in table 25-6. In summary:

- Equation 1 when adjacent onramps do not affect subject ramp behavior.
- Equation 2 addresses cases with an adjacent upstream off-ramp.
- Equation 3 addresses cases with an adjacent downstream off-ramp.

If the choice is between equations 2 and 1, use:

$$L_{EQ} = 0.0675\,(v_F + v_R) + 0.46L_A + 10.24S_{FR} - 757$$

- If $L_{up} \geq L_{EQ}$, Equation 1 is used, else Equation 2 is used

If choice is between equations 3 and 1, use:

$$L_{EQ} = \frac{v_D}{0.3596 + 0.001149\,L_A}$$

- If $(L_{down} \geq L_{EQ})$, Equation 1 is used, else Equation 3 is used.

For any other ambiguity, use largest value of $\boldsymbol{P_{FM}}$

The total departing freeway flow ($V_F + V_R$) may exceed the capacity of the downstream freeway segment. Failure (LOS F) is expected, and queues will form upstream from the merge segment.

- When the downstream freeway capacity is exceeded, LOS F exists regardless of whether the flow rate entering the ramp influence area exceeds its capacity.

When the total flow entering the ramp influence area (V_{R12}) exceeds its maximum desirable level but the total freeway flow (V) does not exceed the capacity of the downstream freeway segment.

- In this case, locally high densities are expected, but no queuing is expected on the freeway. Overall, operation will remain stable, and LOS F is not expected to occur.

OFF-RAMP INFLUENCE AREA FLOW

EXHIBIT 25-12. MODELS FOR PREDICTING V_{12} AT OFF-RAMPS

$v_{12} = v_R + (v_F - v_R)P_{FD}$		
For 4-lane freeways (2 lanes each direction)	$P_{FD} = 1.00$	
For 6-lane freeways (3 lanes each direction)	$P_{FD} = 0.760 - 0.000025v_F - 0.000046v_R$	(Equation 5)
	$P_{FD} = 0.717 - 0.000039v_F + 0.184v_U/L_{up}$	(Equation 6)
	$P_{FD} = 0.616 - 0.000021v_F + 0.038v_D/L_{down}$	(Equation 7)
For 8-lane freeways (4 lanes each direction)	$P_{FD} = 0.436$	(Equation 8)

The variables used in Exhibit 25-12 are defined as follows:

- v_{12} = flow rate in lanes 1 and 2 of freeway immediately upstream of diverge (pc/h),
- v_F = freeway demand flow rate immediately upstream of diverge (pc/h),
- v_R = off-ramp demand flow rate (pc/h),
- v_U = demand flow rate on adjacent upstream ramp (pc/h),
- v_D = demand flow rate on adjacent downstream ramp (pc/h),
- P_{FD} = proportion of through freeway flow remaining in Lanes 1 and 2 immediately upstream of diverge,
- L_{up} = distance to adjacent upstream ramp (m), and
- L_{down} = distance to adjacent downstream ramp (m).

EXHIBIT 25-13. SELECTING EQUATIONS FOR P_{FD} FOR SIX-LANE FREEWAYS

Adjacent Upstream Ramp	Subject Ramp	Adjacent Downstream Ramp	Equation(s) Used
None	Off	None	Equation 5
None	Off	On	Equation 5
None	Off	Off	Equation 7 or 5
On	Off	None	Equation 6 or 5
Off	Off	None	Equation 5
On	Off	On	Equation 6 or 5
On	Off	Off	Equation 7, 6, or 5
Off	Off	On	Equation 5
Off	Off	Off	Equation 7 or 5

If the choice is between equations 6 and 5, use:

$$L_{EQ} = \frac{v_U}{0.2337 + 0.000076 v_F - 0.00025 v_R}$$

- If $L_{up} \geq L_{EQ}$, Equation 5 is used, else Equation 6 is used

If choice is between equations 7 and 5, use:

$$L_{EQ} = \frac{v_D}{3.79 - 0.00011 v_F - 0.00121 v_R}$$

- If ($L_{down} \geq L_{EQ}$), Equation 5 is used, else Equation 7 is used.

For any other ambiguity, use largest value of $\boldsymbol{P_{FD}}$

DENSITY

The on-ramp density D_R is given by:

$$D_R = 3.402 + 0.00456v_R + 0.0048v_{12} - 0.01278L_A$$

where

- D_R = density of merge influence area (pc/km/ln),
- v_R = on-ramp peak 15-min flow rate (pc/h),
- v_{12} = flow rate entering ramp influence area (pc/h), and
- L_A = length of acceleration lane (m).

The off-ramp density D_R is given by:

$$D_R = 2.642 + 0.0053v_{12} - 0.0183L_D$$

- D_R = density of diverge influence area (pc/km/ln),
- v_{12} = flow rate entering ramp influence area (pc/h), and
- L_D = length of deceleration lane (m).

SPEED COMPUTATIONS

	Average Speed in Ramp Influence Area (km/h)	Average Speed in Outer Lanes of Ramp Influence Area (km/h)
Merge areas (on-ramps)	$S_R = S_{FF} - (S_{FF} - 67)M_s$ $M_s = 0.321 + 0.0039\, e^{(v_{R12}/1000)} - 0.004(L_A S_{FR}/1000)$	$S_O = S_{FF}$ where $v_{OA} < 500$ pc/h $S_O = S_{FF} - 0.0058(v_{OA} - 500)$ where $v_{OA} = 500$ to 2300 pc/h $S_O = S_{FF} - 10.52 - 0.01(v_{OA} - 2300)$ where $v_{OA} > 2300$ pc/h
Diverge areas (off-ramps)	$S_R = S_{FF} - (S_{FF} - 67)D_s$ $D_s = 0.883 + 0.00009v_R - 0.008S_{FR}$	$S_O = 1.06S_{FF}$ where $v_{OA} < 1000$ pc/h $S_O = 1.06S_{FF} - 0.0062(v_{OA} - 1000)$ where $v_{OA} \geq 1000$ pc/h

S_R = space mean speed of vehicles within ramp influence area (km/h); for merge areas, this includes all vehicles in v_{R12}; for diverge areas, this includes all vehicles in v_{12};

S_O = space mean speed of vehicles traveling in outer lanes (Lanes 3 and 4, where they exist) within 450-m length range of ramp influence area (km/h);

S_{FF} = free-flow speed of freeway approaching merge or diverge area (km/h);

S_{FR} = free-flow speed of ramp (km/h);

L_A = length of acceleration lane (m);

v_R = flow rate on ramp (pc/h);

v_{R12} = sum of flow rates for ramp (v_R) and vehicles entering ramp influence area in Lanes 1 and 2 (v_{12}) at a merge area (pc/h);

v_{OA} = average per-lane flow rate in outer lanes (Lanes 3 and 4, where they exist) at beginning of ramp influence area (pc/h/ln);

M_s = intermediate speed determination variable for merge area; and

D_s = intermediate speed determination variable for diverge area.

AVERAGE SPEED

$$v_{OA} = \frac{v_F - v_{12}}{N_O}$$

v_{OA} = average per-lane demand flow in outer lanes (pc/h/ln),
N_O = number of outside lanes in one direction (not including acceleration or deceleration lanes or Lanes 1 and 2),
v_F = total approaching freeway flow rate (pc/h), and
v_{12} = demand flow rate approaching ramp influence area (pc/h).

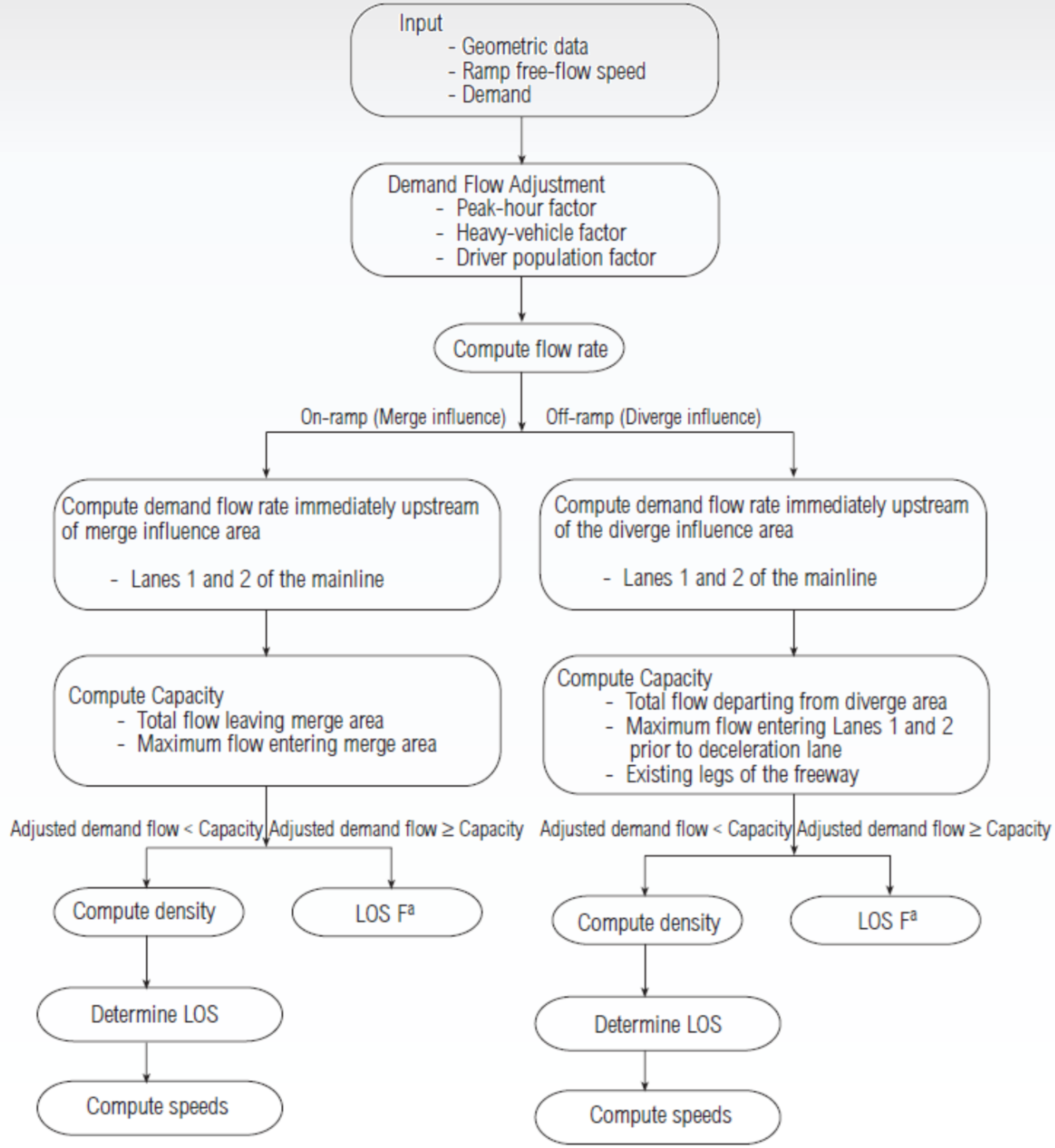
Merge

$$S = \frac{v_{R12} + v_{OA}N_O}{\left(\frac{v_{R12}}{S_R}\right) + \left(\frac{v_{OA}N_O}{S_O}\right)}$$

Diverge

$$S = \frac{v_{12} + v_{OA}N_O}{\left(\frac{v_{12}}{S_R}\right) + \left(\frac{v_{OA}N_O}{S_O}\right)}$$

EXHIBIT 25-1. RAMPS AND RAMP JUNCTIONS METHODOLOGY



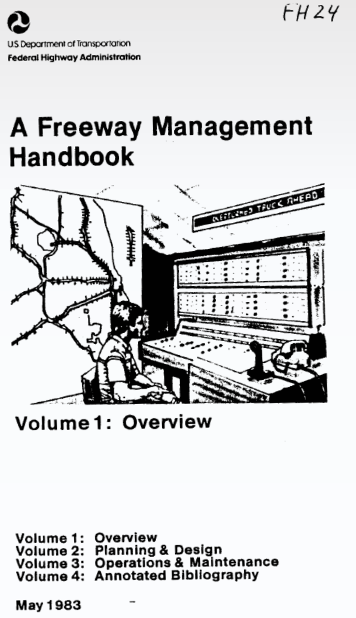
EXAMPLE

An off-ramp (single-lane) pair, 225 m apart, exists on a six-lane freeway. The length of the first deceleration lane is 150 m and that of the second deceleration lane is 90 m. What is the LOS during the peak hour for the first off-ramp?

- √ One-lane off-ramps,
- √ FFS = 100 km/h for freeway,
- √ Rolling terrain,
- √ PHF = 0.95,
- √ 0 percent RVs,
- √ Drivers are regular commuters,
- √ FFS = 60 km/h for first off-ramp,
- √ Three-lane (in one direction) freeway segment,
- √ 5 percent trucks on freeway and off-ramps,
- √ Freeway volume = 4,500 veh/h, and
- √ First off-ramp volume = 300 veh/h.

INCIDENT DELAY

The *A Freeway Management Handbook* provides standardised delay models for highway incidents management.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US Department of Transportation
Federal Highway Administration

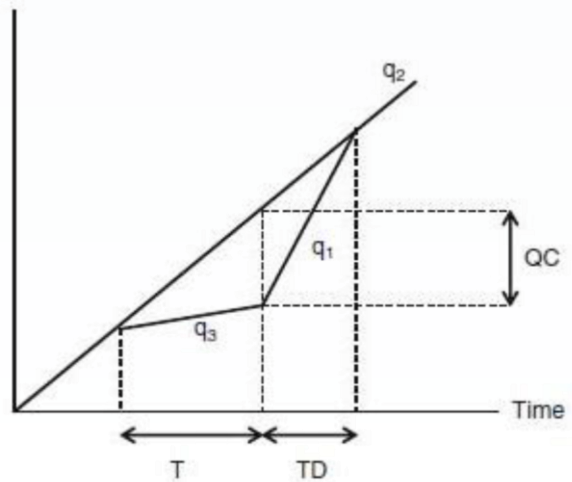
A Freeway Management Handbook

Volume 1: Overview

Volume 1: Overview
Volume 2: Planning & Design
Volume 3: Operations & Maintenance
Volume 4: Annotated Bibliography

May 1983

$$D = \frac{T^2(q_1 - q_3)(q_2 - q_3)}{2(q_1 - q_2)}$$



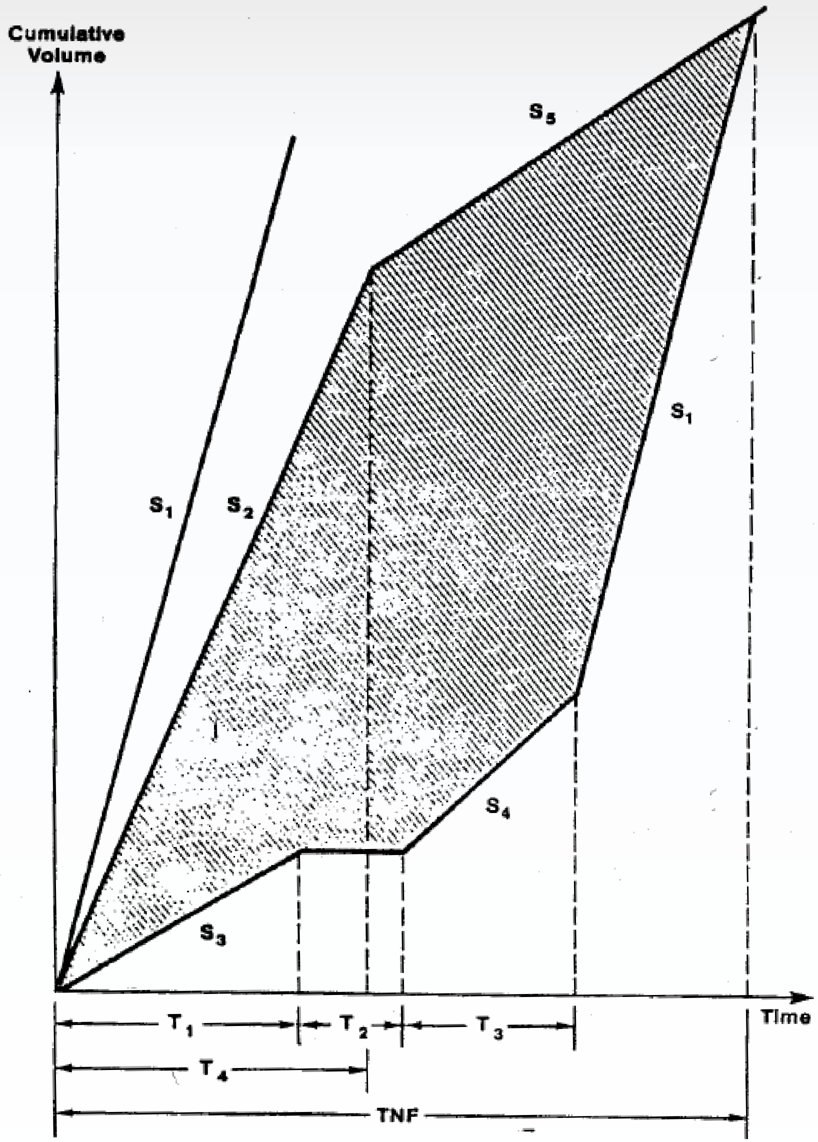


Figure 3.2. General Delay Condition

Figure 3.2, Continued

LEGEND:

S_1	-	capacity flow rate of the facility (vehicles/hour)
S_2	-	initial demand flow rate (vehicles/hour)
S_3	-	initial bottleneck flow rate (vehicles/hour)
S_4	-	adjusted bottleneck flow rate (vehicle/hour)
S_5	-	revised demand flow rate (vehicles/hour)
T_1	-	incident duration until first change (hours)
T_2	-	duration of total closure (hours)
T_3	-	incident duration under adjusted flow (hours)
T_4	-	elapsed time under initial demand (hours)
D	-	total delay (vehicle-hours)
TNF	-	total elapsed time until normal flow resumed (hours)

Note: T_4 is independent of other times.

To compute delay under general conditions:

$$D = \Big[T_1^2 (S_1-S_3)(S_5-S_3) + T_2^2 S_1 S_5 + T_3^2 (S_1-S_4)(S_5-S_4) - T_4^2 (S_1-S_2)(S_2-S_5) + 2T_1 T_2 S_1 (S_5-S_3) + 2T_1 T_3 (S_1-S_4)(S_5-S_3) + 2T_1 T_4 (S_1-S_3)(S_2-S_5) + 2T_2 T_3 S_5 (S_1-S_4) + 2T_2 T_4 S_1 (S_2-S_5) + 2T_3 T_4 (S_1-S_4)(S_2-S_5)\Big] / 2 (S_1-S_5)$$

To compute time until normal flow resumes:

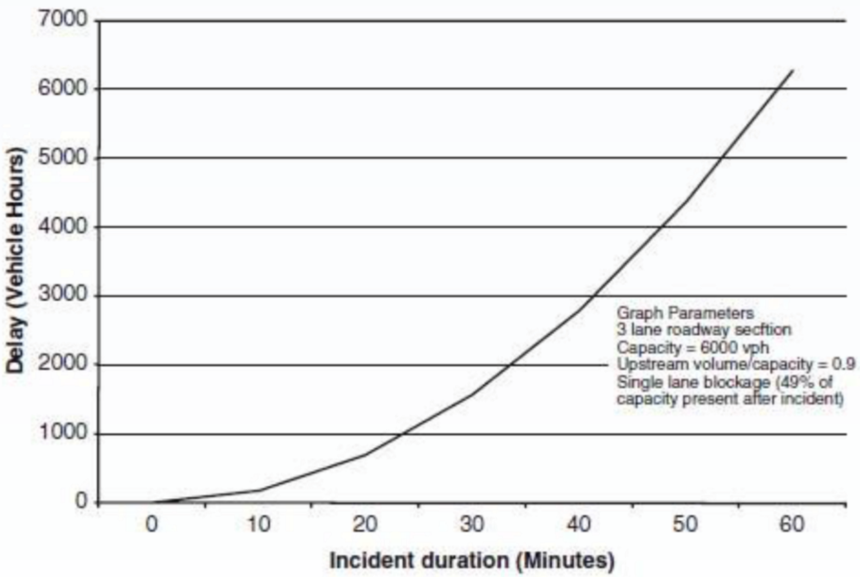
$$TNF = \frac{T_1 (S_1 - S_3) + T_2 S_1 + T_3 (S_1 - S_4) + T_4 (S_2 - S_5)}{(S_1 - S_5)}$$

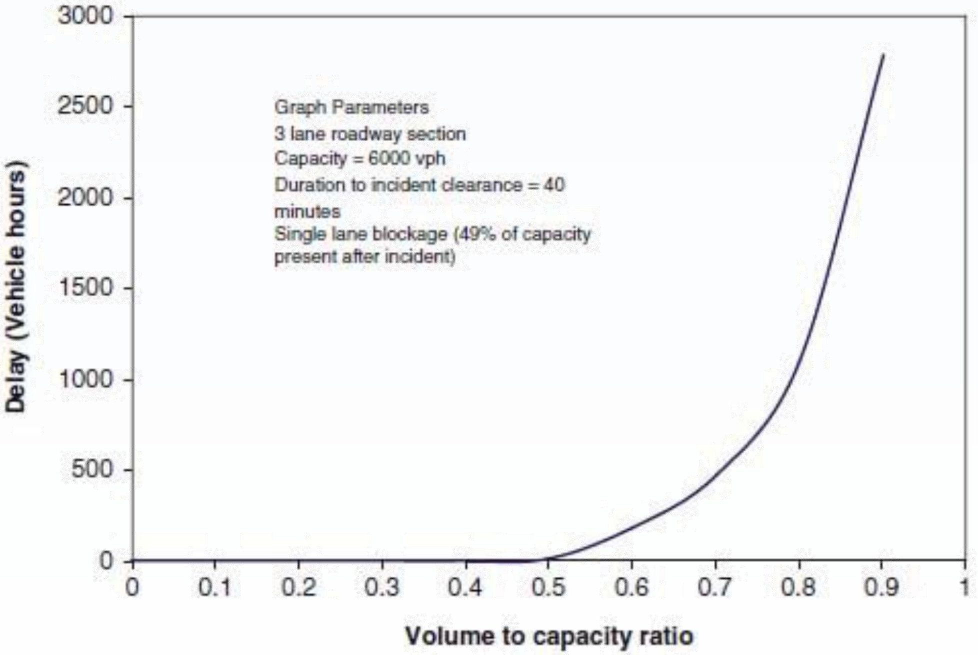
EXAMPLE

A 4-lane highway section serves 5500 pc/h. An accident occurs between two vehicles, immediately closing 3 lanes. The first vehicle, on the third lane is towed after 25 minutes. The other vehicle, occupying lanes 1 and 2, requires vehicle extrication. This operation lasts 74 minutes total. After 45 minutes, demand decreases by 15% in response to the congestion.

Calculate the delay and the time to dissipation.

EFFECTS ON DELAY





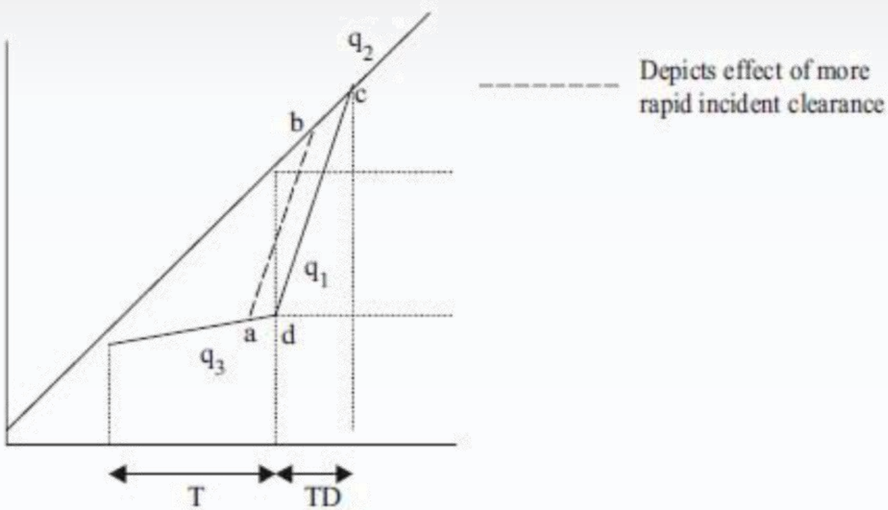
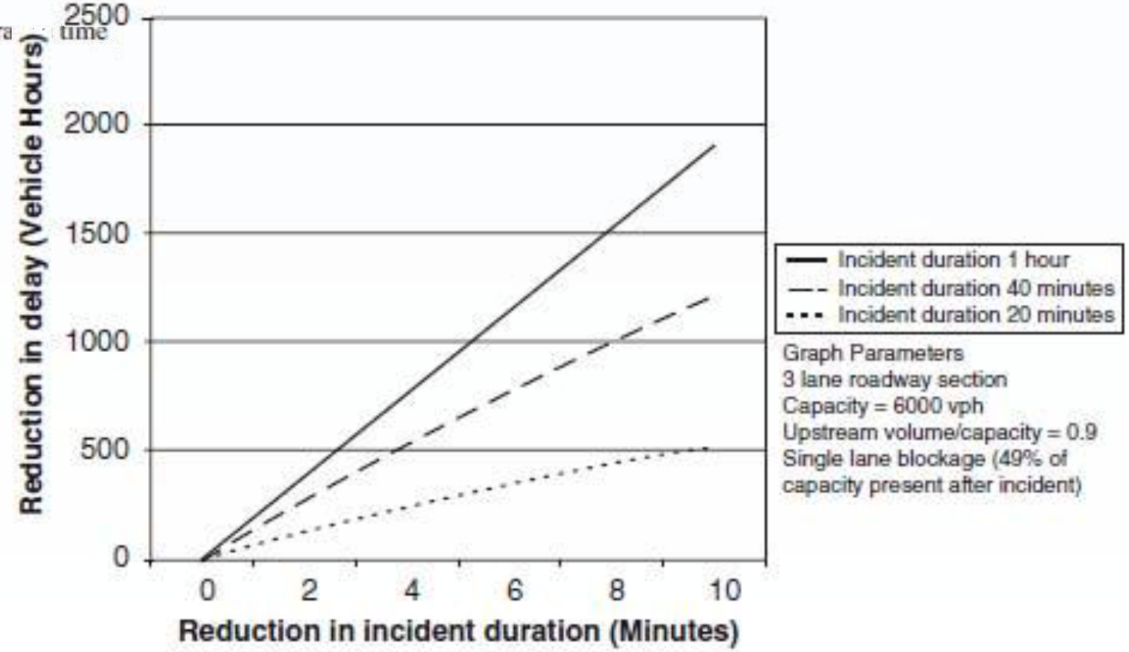


Fig. 4.7 Delay reduction resulting from reduction in incident cleara time



That's all for today!