King Saud University
College of Engineering
Civil Engineering Department

CE 431: Highway Engineering
Tutorial Note 1: Chapter 4
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4.1 Determine the basic section cost for passenger cars using a multilane highway under the following conditions:

Design speed = 60 mph	**Average running speed = 37 mph**	**Grade = +2%**
Volume / capacity ratio = 0.7	**Level of service = C**	**Curvature, R = 1432 ft.**

Enter the graphs in figure 4-1 using average running speed or v/c ratio

(a) Time costs = 27 X $3.00 = $81

(b) Tangent running costs = $79

Find the degree of curvature:

$$\theta = \frac{\left(\frac{180}{\pi} \times 100\right)}{R} = \frac{\left(\frac{180}{\pi} \times 100\right)}{1432} \approx 4^{\circ}$$

(c) Added running costs due to curves = $8

(d) Added cost due to speed changes = $4

Total = $172/1000 vehicle mile

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4.2 Estimate the one-way section transition cost for the highway described in problem 4.1 given that the average running speed on adjacent section is 25 mph. What would be the adjustment factor to account for the presence of 10 percent single unit trucks and 5 percent 3-S2 combination trucks?

Using Figure 4-2 with speed on the slower section = 25 mph and speed on the faster section = 37 mph (From Problem 4.1),

One-way transition costs = $2.40/1000 passenger cars

(b) From Figure 4-2,

Adjustment factor for truck traffic = 1.68

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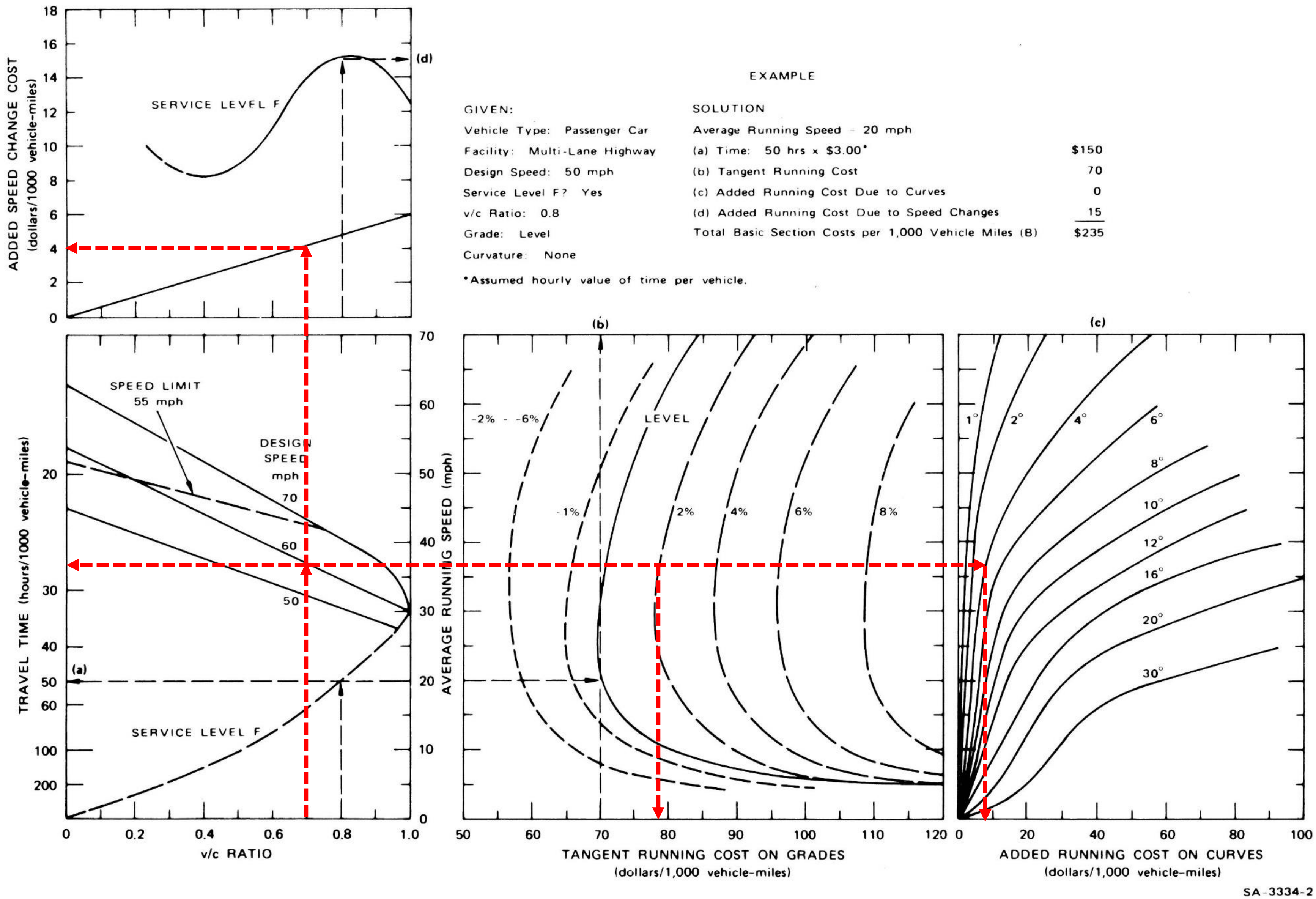
ADDED SPEED CHANGE COST (dollars/1000 vehicle-miles)
SERVICE LEVEL F
(d)
EXAMPLE
GIVEN:
Vehicle Type: Passenger Car
Facility: Multi-Lane Highway
Design Speed: 50 mph
Service Level F? Yes
v/c Ratio: 0.8
Grade: Level
Curvature: None
*Assumed hourly value of time per vehicle.
SOLUTION
Average Running Speed = 20 mph
(a) Time: 50 hrs x $3.00* $150
(b) Tangent Running Cost 70
(c) Added Running Cost Due to Curves 0
(d) Added Running Cost Due to Speed Changes 15
Total Basic Section Costs per 1,000 Vehicle Miles (B) $235
TRAVEL TIME (hours/1000 vehicle-miles)
SPEED LIMIT 55 mph
DESIGN SPEED mph
70
60
50
(a)
SERVICE LEVEL F
v/c RATIO
AVERAGE RUNNING SPEED (mph)
(b)
-2% - -6%
LEVEL
-1%
2%
4%
6%
8%
TANGENT RUNNING COST ON GRADES (dollars/1,000 vehicle-miles)
(c)
1°
2°
4°
6°
8°
10°
12°
16°
20°
30°
ADDED RUNNING COST ON CURVES (dollars/1,000 vehicle-miles)
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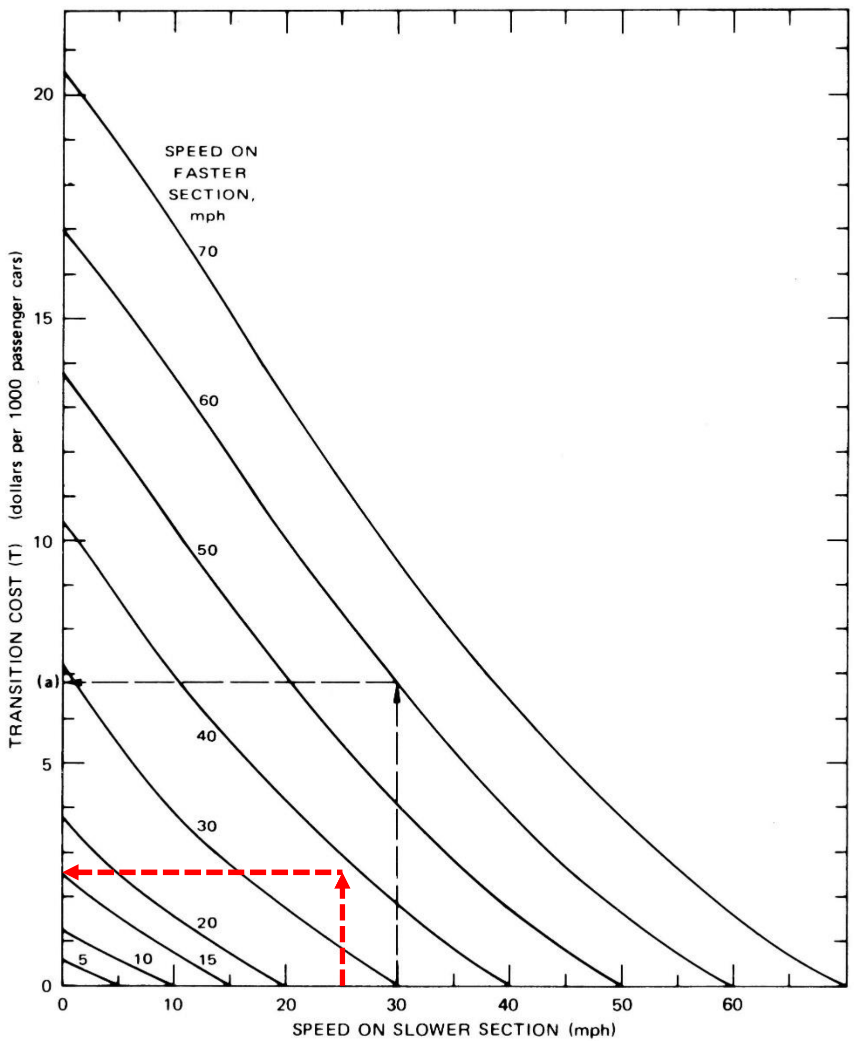

ADJUSTMENT FACTORS FOR TRUCK TRAFFIC

SINGLE UNIT TRUCKS (percent)	3-S2 COMBINATION TRUCKS (percent)											
	0	1	2	3	4	5	6	8	10	20	50	100
0	1.00	1.10	1.19	1.29	1.38	1.48	1.57	1.77	1.96	2.92	5.79	10.58
1	1.02	1.12	1.21	1.31	1.40	1.50	1.59	1.79	1.98	2.94	5.81	-
2	1.04	1.14	1.23	1.33	1.42	1.52	1.61	1.81	2.00	2.96	5.83	-
3	1.06	1.16	1.25	1.35	1.44	1.54	1.63	1.83	2.02	2.98	5.85	-
4	1.08	1.18	1.27	1.37	1.46	1.56	1.65	1.85	2.04	3.00	5.87	-
5	1.10	1.20	1.29	1.39	1.48	1.58	1.67	1.87	2.06	3.02	5.89	-
6	1.12	1.22	1.31	1.41	1.50	1.60	1.69	1.89	2.08	3.04	5.91	-
8	1.16	1.26	1.35	1.45	1.54	1.64	1.73	1.93	2.12	3.08	5.93	-
10	1.20	1.30	1.40	1.49	1.58	1.68	1.77	1.97	2.14	3.12	5.97	-
20	1.41	1.50	1.60	1.70	1.78	1.88	1.94	2.17	2.34	3.32	6.17	-
50	2.02	2.12	2.21	2.31	2.39	2.49	2.58	2.78	2.95	3.93	6.78	-
100	3.04	-	-	-	-	-	-	-		-		-

EXAMPLE

GIVEN:

A stream of traffic consists of 5% single unit trucks and 10% combination trucks. The traffic is travelling at 60 mph and enters a slower section on which the speed is 30 mph.

SOLUTION:

(a) Passenger Car Cost - $6.75

T - $6.75 x 2.06

= $13.91 per 1000 Vehicles

4.3 The volume of traffic along a certain intersection approach is 600 passenger cars per hour. Determine the cost due to stopping (excluding idling) at the intersection under the following conditions:

Saturation flow, s = 1750 vph	**signal cycle time = 60 sec**	**effective green time = 30 sec**
Approach speed = 35 mph	**5% single unit trucks**	**10% 3-S2 combination trucks**

The green/cycle ratio, $\lambda = 30/60 = 0.5$

Capacity of approach = $s \times \lambda$ = 1750 X 0.5 = 875 vph

Degree of saturation, χ = volume/capacity = 600/875 = 0.69

From Figure 4-3,

(a) Average stops per vehicle = 0.76

(b) Stopping delay per signal = 3.1 hours/1000 vehicle per signal

(c) Costs of stopping = $13.50

Time costs	= 3.1 X $3.00 = $9.30
Running cost	= $13.50
Total cost due to stopping (excluding delays)	= $22.80 per 1000 vehicles/signal

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4.4 For the conditions described in problem 4.3, determine the cost due to idling.

From Figure 4-4,

(a) Average delay per vehicle = 16.0 sec

(b) Correction to average delay = 0

(c) Idling time = 4.4 hours/1000 passenger cars

(d) Idling cost = $1.30/1000 passenger cars

Total delay cost	= 4.4 X $3.00/hour = $13.20
Total idling cost	= 1.30
Total cost due to idling	= $14.50/1000 vehicles per signal

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EXAMPLE

GIVEN:

Volume: 480 vehicles/hr
Saturation Flow: 1,600 vehicles/hr
Signal Cycle Time: 60 sec
Effective Green Time: 30 sec
Intersection Approach Speed: 30 mph
5% Single Unit Trucks
5% 3-S2 Combination Trucks

SOLUTION:

λ = 30/60 - 0.5
Capacity of Approach = 0.5 × 1600 - 800
λ = 480/800 = 0.6
(a) Average Stops per Vehicle (per Signal): 0.71
(b) Stopping Delay per Signal: 2.5 hrs
(c) Cost of Stopping: $10.30

Time Cost: 2.5 × $3.00* × 1.35†	$10.13
Running Cost: $10.30 × 1.42†	14.63
Total Cost Due to Stopping per 1,000 vehicles per Signal (excludes idling)	$24.76

*Assumed hourly value of time per passenger car.
†Adjustment factors for trucks in traffic stream.

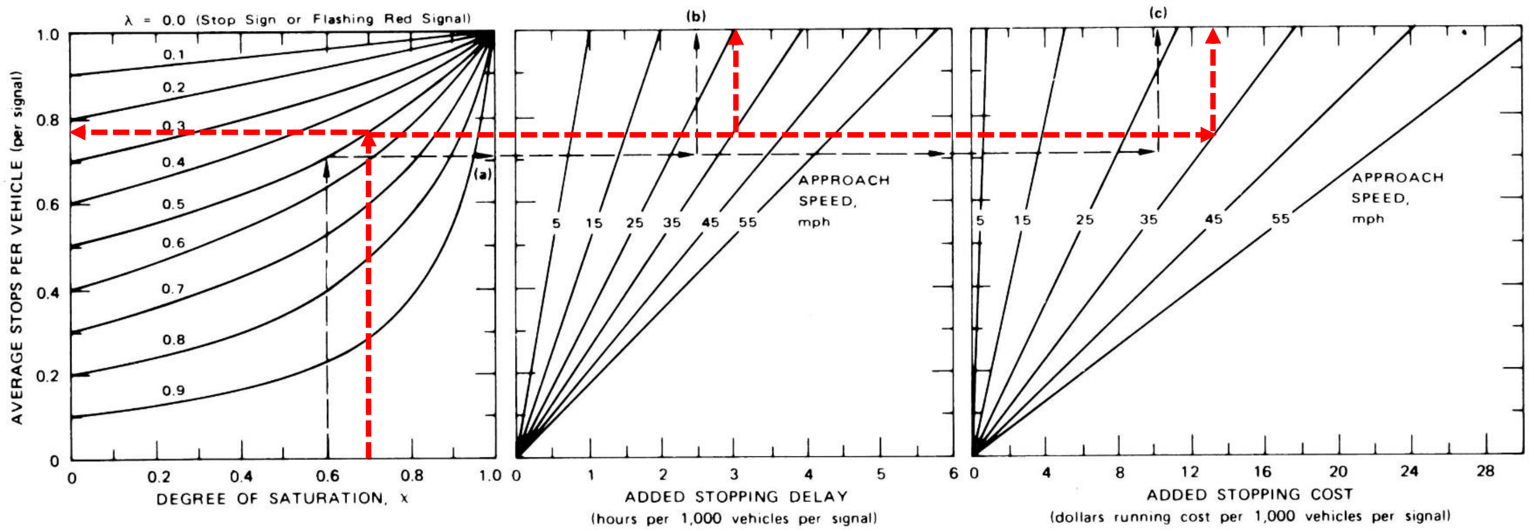
ADJUSTMENT FACTORS FOR PERCENT TRUCKS IN TRAFFIC STREAM

TIME COST

APPROACH SPEED (mph)	SINGLE UNIT TRUCKS (percent)	3 S-2 COMBINATION DIESEL TRUCKS (percent in traffic stream)				
		0	5	10	20	100
5-20	0	1.00	1.15	1.30	1.61	4.03
	5	1.07	1.22	1.37	1.67	
	10	1.13	1.28	1.43	1.74	
	20	1.26	1.41	1.57	1.87	
	100	2.31				
21-40	0	1.00	1.25	1.51	2.01	6.05
	5	1.10	1.35	1.60	2.11	
	10	1.20	1.45	1.70	2.21	
	20	1.40	1.65	1.90	2.41	
	100	2.99				
41-60	0	1.00	1.41	1.82	2.63	9.17
	5	1.11	1.56	1.93	2.74	
	10	1.22	1.61	2.04	2.85	
	20	1.44	1.85	2.26	3.07	
	100	3.20				

RUNNING COST

APPROACH SPEED (mph)	SINGLE UNIT TRUCKS (percent)	3 S-2 COMBINATION DIESEL TRUCKS (percent in traffic stream)				
		0	5	10	20	100
5-20	0	1.00	1.35	1.70	2.40	8.02
	5	1.08	1.43	1.78	2.49	
	10	1.16	1.51	1.86	2.57	
	20	1.32	1.68	2.03	2.73	
	100	2.62				
21-40	0	1.00	1.35	1.71	2.41	8.07
	5	1.07	1.42	1.78	2.48	
	10	1.14	1.49	1.84	2.55	
	20	1.27	1.63	1.98	2.69	
	100	2.37				
41-60	0	1.00	1.35	1.70	2.39	7.96
	5	1.06	1.41	1.76	2.45	
	10	1.12	1.47	1.82	2.51	
	20	1.24	1.59	1.94	2.63	
	100	2.21				



NOTE: Where X = v/λs = v/capacity; s = saturation flow; v = volume; λ = green to cycle time ratio

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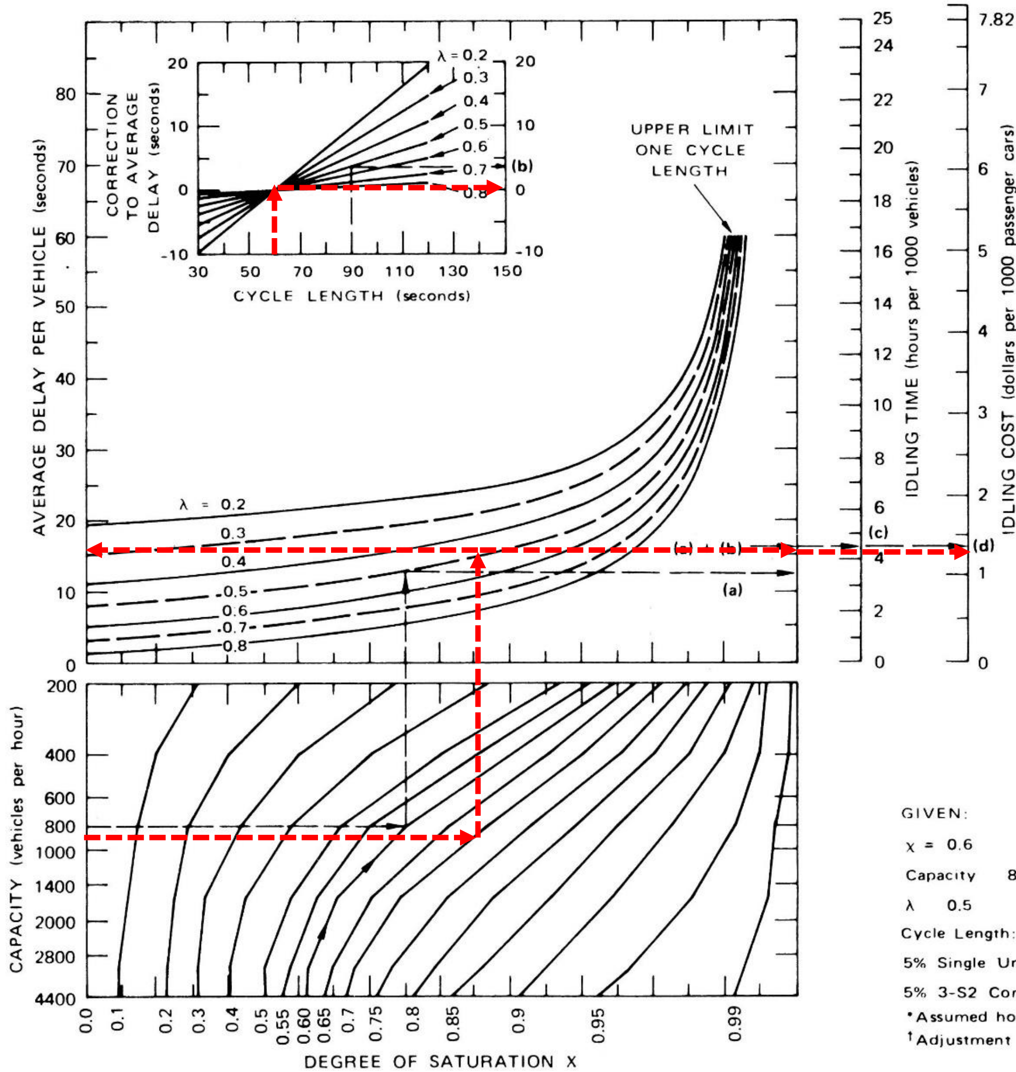

NOTE: Where: $\chi = v/\lambda s$ - v/capacity s = saturation flow v - demand volume λ = green to cycle time ratio

ADJUSTMENT FACTORS FOR PERCENT TRUCKS IN TRAFFIC STREAM

IDLING TIME FACTOR		3-S2 COMBINATION TRUCKS (percent)				
		0	5	10	20	100
SINGLE UNIT TRUCKS (percent)	0	1.00	1.08	1.17	1.33	2.67
	5	1.07	1.15	1.23	1.40	–
	10	1.13	1.22	1.30	1.47	–
	20	1.27	1.35	1.43	1.60	–
	100	2.33	–	–	–	–

IDLING COST FACTOR		3-S2 COMBINATION TRUCKS (percent)				
		0	5	10	20	100
SINGLE UNIT TRUCKS (percent)	0	1.00	0.98	0.96	0.92	0.62
	5	0.99	0.98	0.96	0.92	–
	10	0.99	0.97	0.95	0.91	–
	20	0.98	0.96	0.94	0.90	–
	100	0.89	–	–	–	–

EXAMPLE

GIVEN:

- χ = 0.6
- Capacity 800
- λ 0.5
- Cycle Length: 90 seconds
- 5% Single Unit Trucks
- 5% 3-S2 Combination Trucks

SOLUTION: Average Delay per Vehicle: (a) + (b) 16.2 sec

(c) Idling Hours: 4.5 hrs

(d) Idling Cost: $1.40

Total Delay: 4.5 hrs x $3.00* x 1.15† $15.53

Total Idling Cost: $1.40 x 0.98† 1.38

Total Cost Due to Idling per 1000 Vehicles (per signal) $16.91

*Assumed hourly value of time per passenger car.

†Adjustment factors for percent trucks in traffic stream.

4.9 A certain highway project is planned that would have an initial investment cost of $1.5 million. The user benefits for the facility (in excess of maintenance cost) are estimated to be $105,000 per year over its useful life of 20 years. At the end of the 20-year period, the residual (salvage) value would be $400,000. On the basis of present worth concept, should the project be built? Assume an interest rate of 6 percent. What is the benefit-cost ratio?

The present worth of the user benefits

$$PW_{user} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = \$105{,}000\left[\frac{(1+0.06)^{20} - 1}{0.06(1+0.06)^{20}}\right] = \$1{,}204{,}210$$

The present worth of the residual value

$$PW_{residual} = \frac{F}{(1+i)^n} = \frac{\$400{,}000}{(1+0.06)^{20}} = \$124{,}727$$

The present worth of the combined benefits = $1,328,937

The investment exceeds the benefits by an amount of =$1,500,000 – $1,328,937 = $171,063

The benefit/cost ratio, B/C = 0.88

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4.10 A highway agency is considering two alternative energy attenuation systems, described below, to lessen the severity of crashes into bridge columns and other fixed object hazards. System A has low initial cost but must be repaired extensively after each "hit". System B has high initial cost but needs little maintenance. It is expected that such a device will be hit once every two years. On the basis of present worth concept, which system is preferred? Use an annual interest rate of 7 percent.

	System A	System B
First cost	$3,500	$8,500
Routine annual maintenance	$500	$300
Repair after each hit	$1,200	None
Life	20 years	20 years
Salvage value	$1,000	$2,500

- System A:

$$PW_{residual} = \frac{F}{(1+i)^n} = \frac{\$1{,}000}{(1+0.07)^{20}} = -\$259$$

$$PW_{main} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = \$500\left[\frac{(1+0.07)^{20} - 1}{0.07(1+0.07)^{20}}\right] = +\$5{,}297$$

$$PW_{repair} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = \$1{,}200\left[\frac{(1+0.14)^{10} - 1}{0.07(1+0.14)^{10}}\right] = +\$6{,}260$$

Original investment = +3,500

Total = +14,798

- System B

$$PW_{residual} = \frac{F}{(1+i)^n} = \frac{\$2{,}500}{(1+0.07)^{20}} = -\$646$$

$$PW_{main} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = \$300\left[\frac{(1+0.07)^{20} - 1}{0.07(1+0.07)^{20}}\right] = +\$3{,}178$$

Original investment = +8,500

Total = +11,032

➔ System B is preferred

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4.11 The benefits from a certain highway project are estimated to be $15,000 in the first year and $30,000 in the 31st year. Assuming a uniform growth rate and an interest rate of 8 percent, calculate the present value of benefits over a 20-year analysis period.

The ratio of the future annual volume to the first year volume:

$$\frac{\$30{,}000}{\$15{,}000} = 2.0$$

The average rate of growth

$$r = \frac{\ln(\alpha)}{Y} = \frac{\ln(2.0)}{20} = 0.0346$$

The present worth factor

$$PW_g = \frac{e^{(r-i)n} - 1}{r - i} = \frac{e^{(0.0346-0.08)20} - 1}{0.0346 - 0.08} = 13.1$$

Present value = 13.1 × $15,000 = $197,138

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